BONUS FOLDOUT POSTER!
1.5 million galaxies revealed

March 2008

Astronomy

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SPECIAL ISSUE

ALL ABOUT GALAXIES

- How galaxies came to be
- What happens when galaxies **COLLIDE?**
- How the Milky Way eats its neighbors
- **SECRETS** from starburst galaxies

All you need to see this month's sky events p. 40

Bob Berman on "alien visitation" p. 12

Astronomy's editors answer your questions p. 70

PLUS
HOT NEW PICTURES of Saturn's strangest moon
p. 60

Orion's new binocular telescope tested
p. 72

Graceful arms, gleaming with young stars, embrace the barred spiral galaxy NGC 1300.

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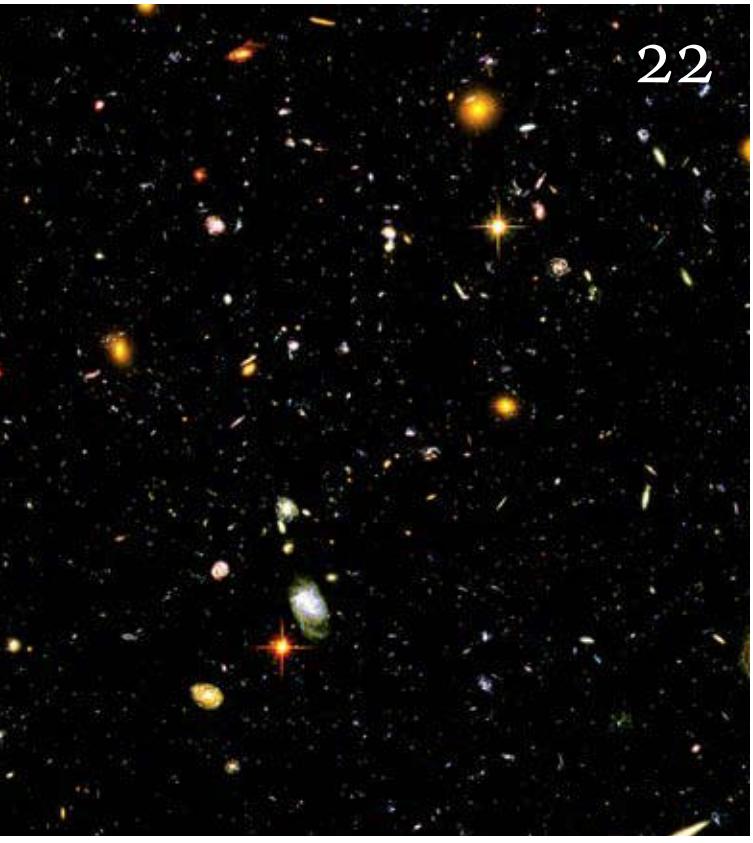

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ASTRONOMY MAGAZINE 35th ANNIVERSARY

Astronomy

VOL. 36, NO. 3

The world's best-selling astronomy magazine

march 2008

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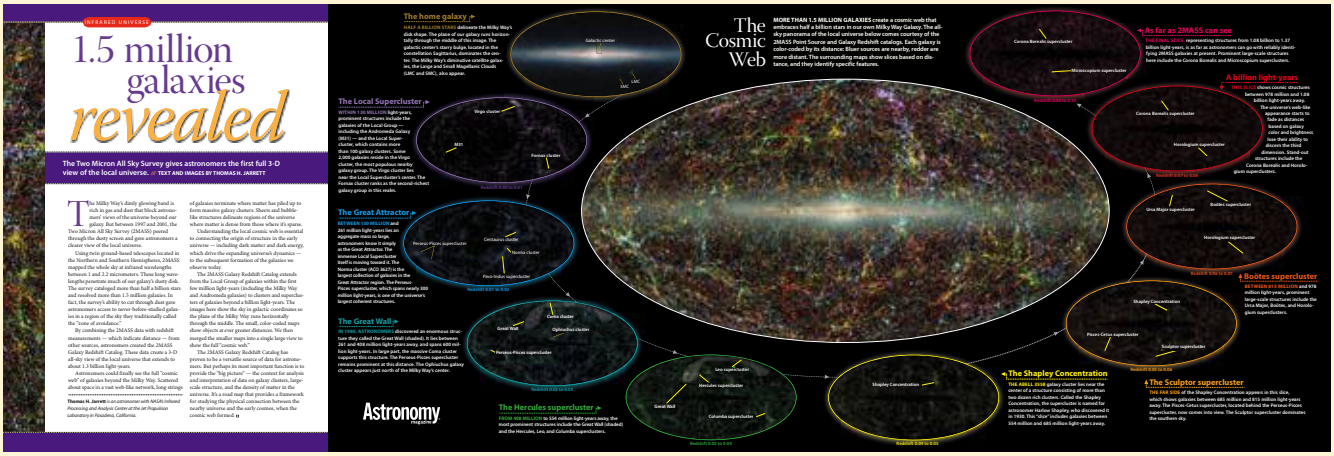
INFRARED UNIVERSE
1.5 million galaxies revealed
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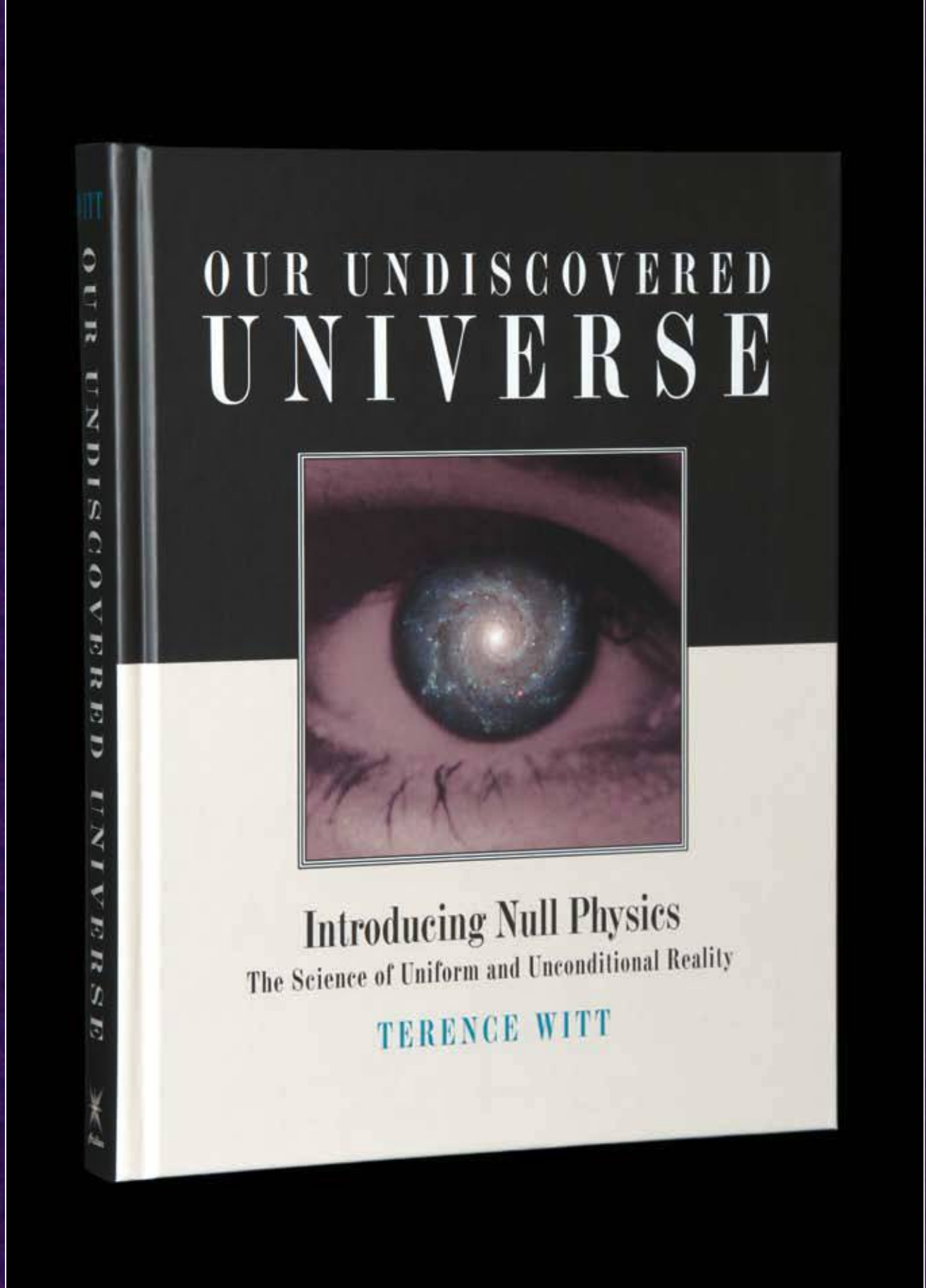
OUR UNDISCOVERED UNIVERSE
OUR UNDISCOVERED UNIVERSE
Introducing Null Physics
The Science of Uniform and Unconditional Reality
TERENCE WITT

Theoretical physics has been hopelessly stalled for over 30 years. Moribund. Ossified. The Standard Model of particle physics uses over 20 ad hoc constants, and no one knows why they are necessary or why they have the values they do. Quantum physics and general relativity remain utterly incompatible. Cosmologists haven't the foggiest idea what could have caused the Big Bang or what, if anything, came before it. And finally, after over 30 years of effort, string theory hasn't even achieved the status of *science*.

There is a very simple reason for this catastrophic, intractable mess. Theorists stopped asking *why* a long time ago. Without the *why*, the search for mathematical symmetries becomes numerology, not science. No telescope or particle accelerator, regardless of its size, is going to tell us *why* the universe is the way it is. When the *why*'s remain unanswered, there is no understanding. When there is no understanding, there is no progress. But this sad situation is about to change forever.

Our Undiscovered Universe is all about the *why*. It's an entirely new paradigm, a premise so powerful that it can finally answer the most important question of all: "*Why does the universe exist?*" This, in turn, reveals many of nature's secrets to a depth and clarity never before imagined.

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100 years ago, Einstein found a small part of the universe's four-dimensional geometry. Null Physics provides the rest of it. After reading this book, concepts like string theory and the Big Bang will seem positively ludicrous in comparison. Here is a brief glimpse of its sweeping unification:

- Energy is a three-dimensional substance, and its most basic unit is time-distance^2.
- Our universe has only a single fundamental constant: its finite, four-dimensional volume.
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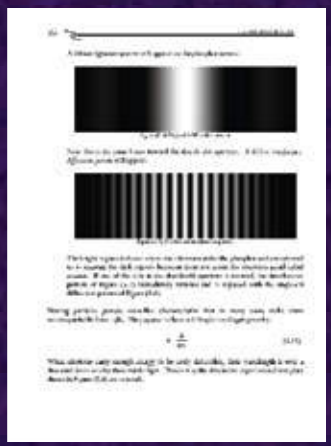
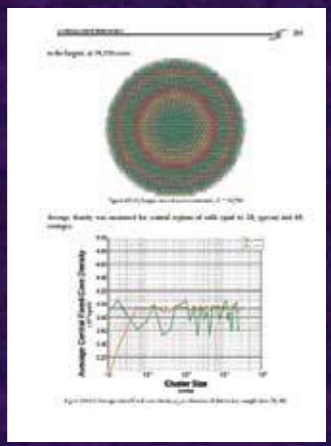
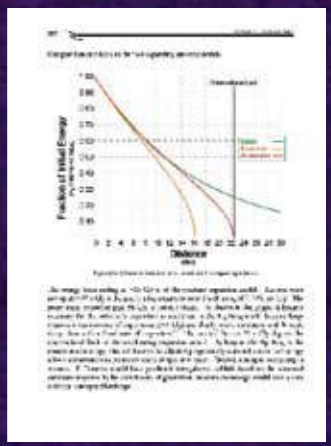

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BY DAVID J. EICHER

The galaxies special issue

Astronomy magazine's staff is a talented, enthusiastic bunch. Our editors listen to everything you tell them — e-mails, letters, online surveys, and cover surveys — and every comment gets read and absorbed. Some of the magazine's most popular issues have been our specially themed editions. We've targeted everything you'd like to know about stars, extrasolar planets, meteorites, cosmology, and the year's top space-science stories. In most of those issues, we included a luxurious foldout poster packed with information.

The popularity of the previous special issues made selecting the next logical topic in a special theme easy — galaxies. This issue devotes more than 35 pages to the hottest news on galaxies.

Leading the pack is Caltech astronomer Richard Ellis' "Quest for the first galaxies" (page 22), which describes ongoing research to understand how galaxies change over time. Ellis gives us a magnificent overview of galaxy formation and the role of cold dark matter, how galaxies clump together, and the nature of black holes. Ellis uses the Keck and Spitzer telescopes, the Hubble Space Telescope, and others, to stay at the forefront of research.

Following this, Contributing Editor Steve Nadis delivers "What happens when galaxies collide?" (page 28). Built around a panoply of computer simulations, this story explores the latest thinking on galaxy mergers. Gravity pulls galaxies together, so they start small and accumulate into larger clumps. Nadis' story explores how such interactions shape the galaxies we see.

Following that lead, University of Toronto astronomer Ray Jayawardhana addresses our galaxy's sordid past in "How the Milky Way devours its neighbors" (page 34). Award-winning author Jayawardhana tackles the story of how the Milky Way has repeatedly swallowed dwarf galaxies, is currently tearing several apart (witness the Sagittarius Dwarf), and will ultimately absorb the Magellanic Clouds.

Associate Editor Daniel Pendick describes starburst galaxies and the role they play in galactic evolution in "Galaxies on fire" (page 64). Such violent, eruptive animals as M82 in Ursa Major hold secrets about how so-called galactic superwinds crush matter together.

And what would a special issue be without a foldout poster? Senior Editor Francis Reddy engineered the one you hold, half of which shows "1.5 million galaxies revealed" in a story by Caltech astronomer Thomas Jarrett. Jarrett's story unravels data from the 2MASS infrared survey that show the local universe in spectacular 3-D glory. On the poster's other side, Reddy gives you a summary of the Sloan Digital Sky Survey and its recent progress in imaging galaxies.

What more could a galaxy fan ask for? Enjoy!

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 36, Number 3

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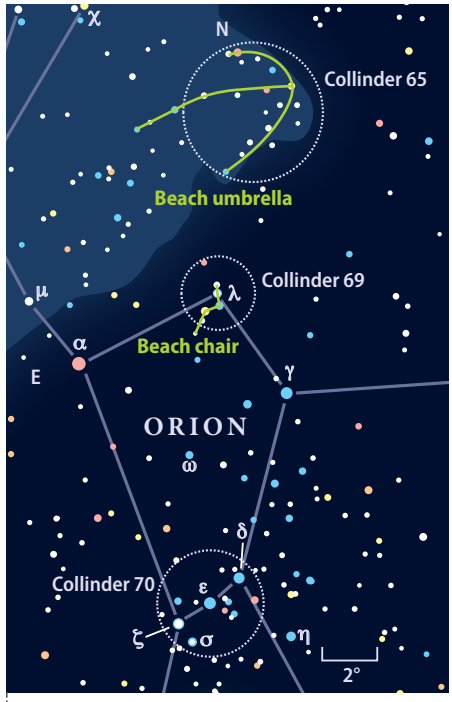
Orion's asterisms

In "The sky's Triangle" (November 2007), Phil Harrington mentions a double asterism — the golf club and golf ball in Andromeda. This made me think of two asterisms I saw in the open star clusters Collinder 65 and Collinder 69 in Orion. Collinder 65, the larger cluster,

contains a D-shaped star group that looks like an umbrella. Orion's head, Collinder 69, includes three stars in a row that form an asterism resembling a beach chair.

The chair and umbrella are oriented 180° to each other, as if the wind has toppled one of them. It's probably the umbrella, because it has a bent pole!

Undoubtedly, it was a cold, crisp winter night that inspired me to imagine objects from a warmer climate. Take a look in your binoculars the next clear night and see if my visions don't warm the cockles of your heart as well. **— HUGH BARTLETT,** OAKLAND, CALIFORNIA



THE BEACH UMBRELLA and beach chair asterisms in winter's Orion foreshadow warmer times to come. *ASTRONOMY:* ROEN KELLY

The big lens in the sky?

While reading "How large will telescopes get?" (July 2007), I noticed a theme repeating: The bigger the lens or primary mirror, the more light gathered, and the farther back in time we can see. Is there any way a telescope in orbit could take advantage of the natural refraction of light by Earth's atmosphere? **— SILAS JACKSON,** LAS VEGAS

Air molecules, airborne contaminants, and dust scatter blue light throughout our atmosphere. That's why a clear sky appears blue. Light passing through, therefore, appears redder than it should. Because of the color shift and light loss, Earth's atmosphere would not provide a "lens" of high-enough quality to image celestial objects. **— MICHAEL E. BAKICH, SENIOR EDITOR**

Serving the stars

Thank you for Geoff Chester's fine piece, "Lighthouse of the skies" (August 2007), about the history of the U.S. Naval Observatory. Chester points out that the Navy's Depot of Charts and Instruments was redesignated the U.S. Naval Observatory and Hydrographic Office in 1854.

The Observatory is not the only institution tracing its origin to the Depot. In 1866, the Naval Observatory and the Hydrographic Office became independent institutions. The Hydrographic Office was renamed the United States Naval Oceanographic Office in 1962.

The office continues to support the fleet from its present location at Stennis Space Center, Mississippi. I am proud to have served a tour of duty there. **— JAMES STEPHENS,** RESEARCH SCIENTIST, DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF SOUTHERN MISSISSIPPI

Philosophical reflections

Bob Berman's "Hall of mirrors" (November 2007) took me back to a philosophy class called "Issues in science and religion." My professor tried to convince the class that the apple on his desk was not an apple at all. Instead, it was merely our perception of it as an apple.

My first thought was, "He's a product of the 1960s' love for herbs." After getting a less than passing grade on my first exam, I came around to his point of view. The next time I observe the Moon with my perceived telescope, I think I'll have what I perceive to be a hot dog, with perceived mustard and relish. **— TIM WEIBLE,** DEFIANCE, OHIO

Let's hear it for gravity!

I take issue with your August 2007 cover story, "The ugly side of gravity." Gravity, as described by Newton and Einstein, is a wondrous force in the universe. But it is a force, after all. It smashes stars to pieces, steers comets into planets, and is responsible for an entire universe full of "stuff" either decelerating or accelerating.

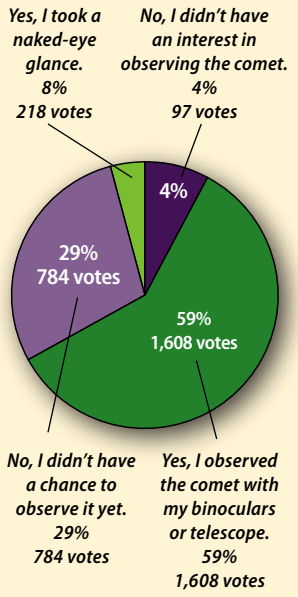
At the risk of sounding sappy, gravity's destructive effects are largely responsible for the creation of new stellar objects upon which future generations will gaze. **— ALEX AVRIETTE,** WASHINGTON

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Webtalk

Online poll results

Did you observe Comet 17P/Holmes?



Total votes: 2,707

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March web extras

Go beyond the stories printed here with these subscriber-only features online. Monthly web extras bring you additional research, interviews, photographs, and animations our editors turned up while creating the magazine stories.

"Quest for the first galaxies" p. 22 Caltech astronomers claim the most distant galaxies ever.

"What happens when galaxies collide?" p. 28
New computer simulations show the warped reality of spiral-galaxy mergers.

"How the Milky Way devours its neighbors" p. 34 Watch the Andromeda and Milky Way galaxies collide.

"Galaxies on fire" p. 64
Even after centuries of observations, galaxy M82 commands astronomers' attention.

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"Orion's new binocular telescope tested" p. 72
Get step-by-step instructions on how to attach the BT70 to a go-to mount.

"Take a small tour of the Big Dog" p. 76
Use binoculars to notch as many Messier objects as you can in a single night.

This month's top blogs

Editors put their spin on current events in the staff blog. You can share your opinions on news headlines and popular culture, too.

1 **SPACE: THE VINYL FRONTIER.** Voyager 1 and 2 carried gold-plated albums into interstellar space. What soundtrack would you have picked to represent humankind? **BY JEREMY McGOVERN**

2 **HOBBIT SOLAR SYSTEM DISCOVERED!** Discoveries of earthlike extrasolar planets are abuzz in the media. The amazing point is that the universe is teeming with planets, whether they're like Earth or not. **BY DANIEL PENDICK**

BY BOB BERMAN

Ask the aliens

Are we being visited by aliens? Seeing is believing, but in 25 years of night flying in my trusty old Piper Cherokee, and in all these years of watching the sky, I've never seen a UFO. Yet, I get letters from seemingly sober folks describing strange sky objects. To learn more about this, I often ask audiences, after I've given a talk, if anyone's seen an unexplained UFO. I figure sky-watchers are the best observers because they're unlikely to mistake Venus for a mothership from the Pleiades.

One or two in every crowd does report an odd sighting. Sometimes they also supply the answer: "After awhile we realized the three bright disks hovering in formation were actually a jet's landing lights."

A few sober-sounding accounts defy explanation — just enough to make me keep a slightly open mind, even though I'm skeptical. Of course you have the nuts, too. The president of the World Chess Federation — who is also president of the Republic of Kalmykia in Russia — claims he was taken aboard a flying saucer. He also believes chess was given to us by aliens.

Some night, I'd love to see a saucer land on the meadow behind my house. I can picture a door opening and a ramp coming down. But before I'd go in, I'd ask the alien pilot some questions.

BB: What's with the ramp? All your saucers have ramps. Our private jets have folding stairs. Is there a rule on your planet that you must provide handicapped access?

Saucerguy: Glyptil Rrrrr.

BB: Here's what bothers me. You're obviously secretive, since you never announce yourselves by landing in, say, Central Park. You appear only in rural places where just one person sees you. Why is that? Are you spooked by cities? Hate litter? Is it that urbanites talk so fast you can't understand them? What gives?

Saucerguy: (Silence)

BB: Where do you go when your ship rises? You can't be orbiting because NASA and the Russians track everything larger than a baseball, and there's nothing up there. Where do you hang out when you're not freaking out farmers?

(I peek in, and it's all bright and empty except for some shiny, humming machines.)

I guess you don't eat because nothing's messy in there. How about coffee? Is that big thing a coffee maker? Do you drink lots of it to stay awake during the long haul between stars? Do you ever nod off and then suddenly twitch and come awake, and you've blown it and are flying somewhere near Uranus?

I SUDDENLY GET IT:
These aliens don't have their act together. They're from a planet of incompetents.

Saucerguy: (Just stares)

BB: Everyone says you have huge eyes, but they never say what color. Hmm, yellow. Nice. Looks like *Star Trek*'s Data, or maybe a cat. Speaking of which, what about all those medical procedures you supposedly do on cows and horses? Why them? Why not experiment on Earth's annoying little yappy dogs?

Saucerguy: (Blinks once)

BB: In the book *Communion*, author Whitley Strieber says you perform operations on your abductees. Is that considered elective surgery? Do people first have to sign anything? Some standard form letting you share the medical info with other saucers? Would you do liposuction on my tummy?

Saucerguy: Rrrrrrr.

BB: That's another thing. People who have been abducted claim they've travelled to other worlds and been given information by aliens. Is this imparted in English? With what accent? When in Georgia I guess you say, "Y'all step in, ya heah?" while during landings in the Australian Outback it's, "Hey mite, cam aboard then." Well? Say something.

Saucerguy: Greetings, we will show you our planet.

BB: That's better. English. And what a deep voice for such a skinny alien. So tell me, is that why you've been hovering around for decades? Just so you can show a few of us your planet? Why not simply beam videos into everyone's iPod? I guess a few people are supposed to see it for themselves so they can be frustrated when no one believes them: "They had this big golden city and it was like, it was like ... well, you had to be there!"

I slide back down the ramp. Let them go. These guys are trying to stay hidden for 50 years, but they're spotted here and there by a few loony farmers and the president of Kalmykia? They keep getting caught like third-rate cat burglars. Or they totally lose control and swerve into Roswell. I suddenly get it: These aliens don't have their act together. They're from a planet of incompetents.

That means they're just like us after all. The aliens have no idea what they're doing. Feeling good about them for the first time, I watch the saucer rise into the night sky and see it barely swerve in time to miss a flock of geese.

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BY STEPHEN JAMES O'MEARA

Orion's phantom loop, part 2

Last month I asked you to look for the emission nebula Sharpless 2–276 in Orion with your unaided eyes. Now I'd like you to try seeing its brightest portion through binoculars or a telescope. ☾ But first let's look at the curious history surrounding the discovery of this 10°-wide semicircle of light surrounding Orion's belt and sword.

Sharpless 2–276 is more commonly known as Barnard's Loop, named for the legendary visual observer and photographic genius Edward Emerson Barnard (1857–1923). Barnard discovered this "great nebula extending in a curved form over the entire body of Orion" on exposures he made in October 1894 with a 1.5-inch "magic-lantern" lens. But Barnard was not the first to discover the nebula.

HERSCHEL MUSEUM

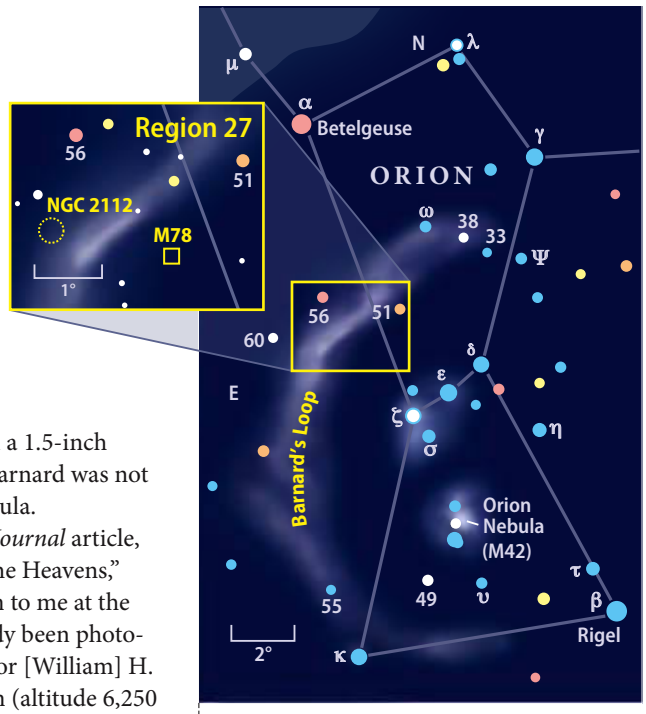
WILLIAM HERSCHEL (1738–1822) spied a particularly bright portion of the nebula now known as Sharpless 2–276 (Barnard's Loop) and labeled it "region 27."

In a 1903 *Astrophysical Journal* article, "Diffused Nebulosities in the Heavens," Barnard reveals, "Unknown to me at the time, this nebula had already been photographed in 1889 by Professor [William] H. Pickering on Mount Wilson (altitude 6,250 feet) in southern California, with a Voigtlander portrait lens of 2.6 inches aperture and 8.6 inches equivalent focus, with an exposure of three hours." Justifiably, then, the nebula could also be called Pickering's Loop, or, as Barnard wrote, "the great curved nebula in Orion."

Herschel's legacy

The discovery of Barnard's Loop came even before Pickering. In his *Astrophysical Journal* article, Barnard also notes that on one of his photographs, "Most of the great curved nebula is clearly shown, especially the region described by Herschel."

Barnard is referring to "region 27," one of several areas of the sky listed by the 18th-century visual astronomer Sir William Herschel (1738–1822) as containing diffused nebulosity. Region 27's coordinates are right ascension 5h48m25s and declination 1°09'53", or about 30' south of the midpoint between the 5th-magnitude stars 56 and 51 Orionis. Barnard noted that region 27 is the nebula's brightest portion.



REGION 27'S "MILKY NEBULOSITY," first described by William Herschel in 1786, harbors the reflection nebula M78 and the star cluster NGC 2112. *ASTRONOMY:* ROEN KELLY

Barnard seemed adamant about this point. Indeed, his 1903 paper was a response to an earlier paper published by English photographer Isaac Roberts (1829–1904), who described his photographic investigation of these Herschel regions. Out of 52 regions, Roberts found only four that showed any trace of nebulosity. Roberts did not image any nebulosity in region 27.

Barnard countered that Roberts' exposures were too short "to test the existence of some of these nebulosities." He also added, "It is a little unreasonable to suppose that Herschel, who made so few blunders compared with the wonderful and varied work that he accomplished, should be so palpably mistaken in forty-eight out of fifty-two observations of this kind." Key to Barnard's argument were his images of the great curved nebula, which, he said,

showed without question "nebulosity exists where Herschel saw it."

No more naked eyes

What I find most interesting in this exchange is that eagle-eyed Barnard — the man who discovered the large, dim California Nebula in Perseus without a telescope — did not attempt to visually confirm the nebulosity in Herschel's region 27.

William Sheehan, author of *The Immortal Fire Within: The Life and Work of Edward Emerson Barnard* (Cambridge University Press, 1995), says Barnard largely gave up his visual observations of nebulae after he started making wide-angle photographs with the 6-inch Willard lens at Lick Observatory in 1889. The lens provided a 20° field of view and had tremendous potential for celestial photography.

"I think he realized," Sheehan explains, "that photography was so much more discerning as a medium for making out these objects. I suppose that the dry-plate photography had about the same impact on nebular studies that CCD imaging has had on planetary studies today — to the point where very few observers bother to make visual observations any longer."

Sweeping region 27

Larry Mitchell of Houston sent me a photocopy of a note Herschel made about region 27. "I am pretty sure the following space is affected with milky nebulosity," Herschel wrote in one of his catalogs.

Herschel then provided us with two boundary positions: a roughly north-south slice through the brightest portion of the great curved nebula — from a point about 1° northwest of 56 Orionis — to a position roughly midway between the reflection nebula M78 and open star cluster NGC 2112. As Barnard noted, this region covers the brightest section of the great curved nebula.

Herschel, like other observers of his day, took advantage of the "sweep" phenomenon to verify the existence of faint nebulae or to determine their sizes. "I used every means of ascertaining [these nebulae] by motion of the telescope," he wrote.

It's only natural. As Robert L. Gregory informs us in his book *Eye and Brain: The Psychology of Seeing* (McGraw-Hill, 1978), the eye's primary function is to detect movement. It's key to our survival. When an image is held steady, vision fades after only a few seconds.

That is why, when searching for an object, our eyes make small, rapid jerks. "[I]t seems," Gregory says, "that part of the function of the eye movements is to sweep the image over the receptors so that they do not adapt and so cease to signal to the brain the presence of the image in the eye."

Instinctively or not, Herschel employed his telescope to maximize his vision. For the same reason, today's observers gently tap their telescope tubes when trying to see a faint deep-sky object. Setting the field in motion sweeps the target back and forth across the retina's periphery, keeping the night-sensitive rod cells on high "alert."

REFLECTION NEBULA M78 lies close to the brightest portion of Barnard's Loop, called region 27. It is part of an even larger realm of nebulosity, the Orion complex. DANIEL GOOD

How to see it

While gentle tube tapping definitely helps the eye see relatively small objects like dim galaxies or planetary nebulae, seeing the nebula in region 27 may require a Herschelian effort. In other words, because the nebula is so large, you will probably have to make generous sweeps with your binoculars or telescope across the region to perceive it, as did Herschel.

In my search for region 27 using a 5-inch refractor at 30x magnification, the technique worked. When I rocked the tube gently back and forth between 56 Orionis and M78, the nebula looked delicate, like an icy railing in snow under the light of a quarter Moon.

I am curious as to how small an aperture can detect this nebula and the sky conditions required. Send your reports to me at someara@interpac.net. Good hunting!

Planets form Dust kicked up by colossal collisions in the Pleiades star cluster (M45) hints that rocky planets are forming there.

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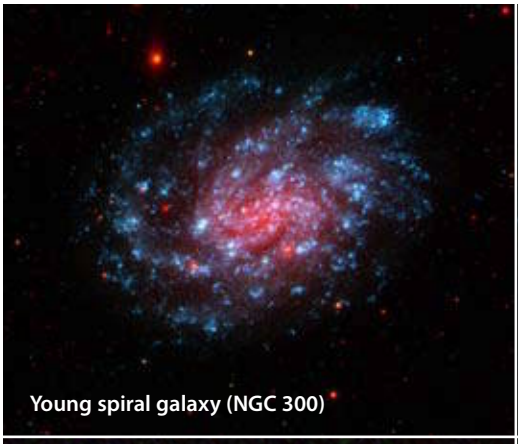
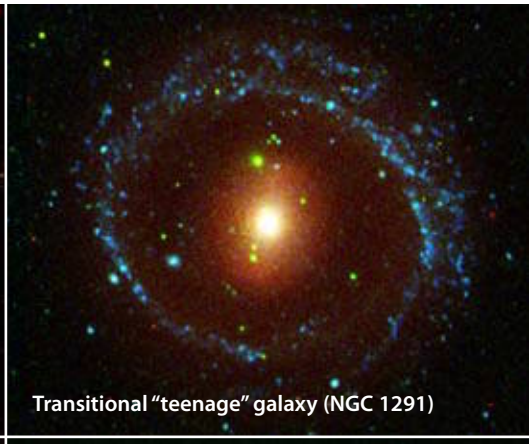
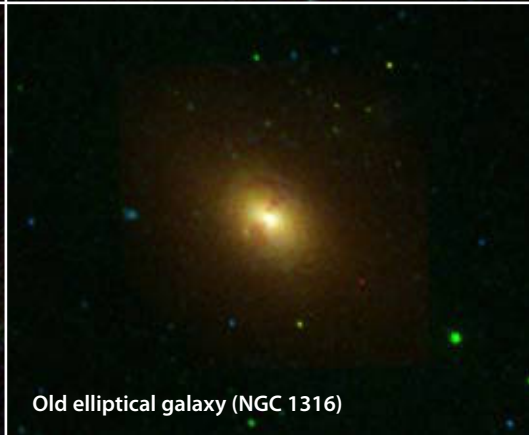

Young spiral galaxy (NGC 300)


Transitional "teenage" galaxy (NGC 1291)

Transitional "teenage" galaxy (NGC 4569)


Old elliptical galaxy (NGC 1316)

◀◀ **PROLIFIC YOUTH.** Star formation runs rampant in spiral galaxies like NGC 300. Young stars in these galaxies shine in blue and ultraviolet light. NASA/JPL-CALTECH/LAS CAMPANAS OBSERVATORY

◀ **TEENAGE SLOWDOWN.** An adolescent galaxy like NGC 1291 shows a marked decrease in star production and less emission of ultraviolet light. NASA/JPL-CALTECH/CTIO

◀◀ **TRANSITIONING TEEN.** Teenage galaxy NGC 4569, a transitional galaxy, has used up much of its star-making material. Such teen galaxies represent an evolutionary link between young spirals and old ellipticals. NASA/JPL-CALTECH/PALOMAR OBSERVATORY

◀ **GOLDEN YEARS.** Elliptical galaxies have consumed their fuel and no longer make stars. Stars in these galaxies emit mostly infrared and red light. NASA/JPL-CALTECH/CTIO

17 Volcanic trio on Mars could erupt again

18 Hubble spies Comet Holmes' heart

18 Uncommon Moon

20 Vanguard 1 satellite marks 50 years in space

Exploring galaxy evolution

NASA's Galaxy Evolution Explorer (GALEX) has spent 5 years observing the ultraviolet light from tens of thousands of galaxies across 9 billion light-years of space. Astronomers now have combined these observations with visible-light data from the Sloan Digital Sky Survey, and confirmed an evolutionary link between spiral and elliptical galaxies.

The "nurture" theory of galaxy evolution posits some galaxies begin their lives as star-forming spirals and evolve over time into less-active ellipticals. To prove these young spirals can grow up to be ellipticals, California Institute of Technology astronomer Chris Martin led a team that looked for — and found — a number of "teenage" galaxies.

These adolescent galaxies are in the midst of transitioning from young to old.

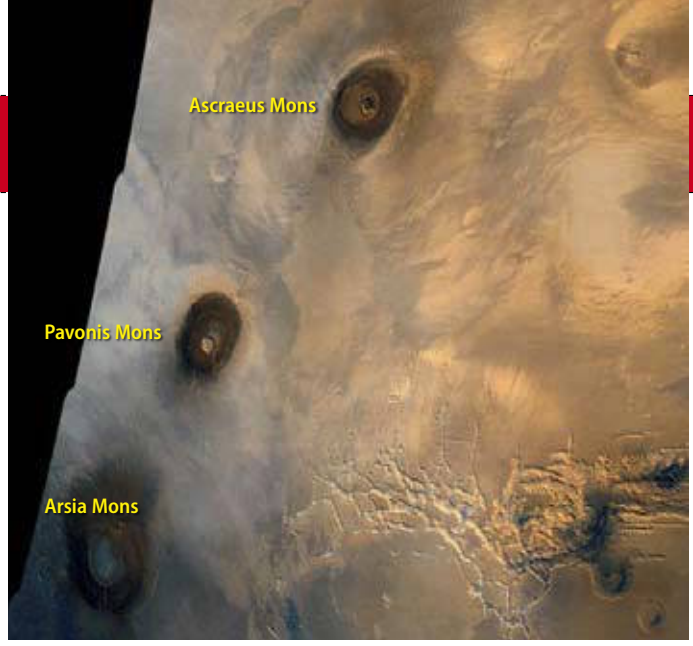
"Our data confirm that all galaxies begin life forming stars," says Martin. They then stop producing stars and settle into old-age ellipticals "through a combination of mergers, fuel exhaustion, and perhaps suppression by black holes," he adds. — **LAURA LAYTON**

Volcanic trio on Mars could erupt again

A chain of three ancient volcanos on Mars could erupt again, say researchers led by Jacob Bleacher of Arizona State University and NASA's Goddard Space Flight Center. Bleacher and his colleagues came to this surprising conclusion after comparing features of the martian trio to volcanos in the Hawaiian Islands.

Collectively known as Tharsis Montes, the three volcanos trend from southwest to northeast. The chain comprises Arsia Mons, Pavonis Mons, and Ascraeus Mons. Each volcano's base spans roughly 185 miles (300 kilometers), and the summits rise at least 9 miles (14 km) above the surrounding plain. As in Hawaii, the members of Tharsis Montes are broad, flat "shield" volcanos, so named because they resemble a warrior's upturned shield.

Bleacher's team spotted features at Tharsis Montes that suggest potential for future volcanic activity. For one thing, the surface near the chain is nearly free of impact craters, indicating relatively recent eruptions covered the surface with lava. The younger the volcanos, the less likely they are to be extinct.



NASA/JPL

CHAIN OF FIRE. The Viking 1 orbiter snapped color images in 1980 for this mosaic of Tharsis Montes and its trio of volcanos.

All three volcanos also lack signs of cinder-cone eruptions. In Hawaii, gas-rich fountains of lightweight lava cinders signal the end of a shield volcano's lifetime. The cinders collect into steep cone-shaped piles that should be visible in recent Mars orbital images, but are notably absent. The researchers reported their results in the September 19 issue of the *Journal of Geophysical Research, Planets*. **— DANIEL PENDICK**

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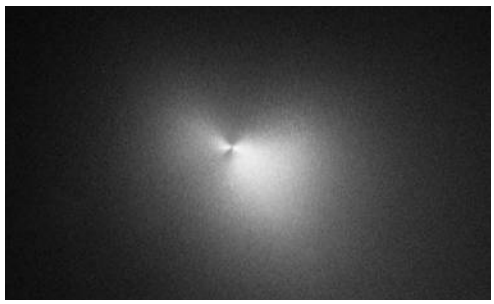
NASA/ESA/A. DYER

BIG BLUE. Comet Holmes appears ghostly in this ground-based image taken November 1, 2007, by astrophotographer Alan Dyer.



NASA/ESA/H. WEAVER (JHU/APL)

DUSTY HEART. Dust surrounds Comet Holmes' nucleus in this Hubble Space Telescope image taken November 4, 2007.

Hubble spies Comet Holmes' heart

Comet 17P/Holmes brightened a million times October 23–25, 2007, giving astronomers a rare glimpse into one of the most mysterious comets yet observed. Now, the Hubble Space Telescope has peered into Comet Holmes' bright core.

Astronomers at Johns Hopkins University (JHU) in Laurel, Maryland, used Hubble to capture images of the comet's core October 29, October 31, and November 4. They're looking for clues as to what caused the comet to brighten.

The object's asymmetrical appearance results from the distribution of concentric dust shells near its nucleus. About twice as much dust lies east-west as along north-south. Using previous Hubble observations in 1999, astronomers estimate the comet's nucleus has a diameter of about 2.1 miles (3.4 kilometers). Holmes also has a faint tail.

Astronomers studying Hubble's up-close images of Comet 17P/Holmes hope to learn more about the structure of its nucleus. "Most of what Hubble sees is sunlight scattered from microscopic particles," says Hal Weaver of JHU's Applied Physics Laboratory, who led the Hubble investigation. "But we may finally be starting to detect the emergence of the nucleus itself" in these most recent Hubble images, Weaver adds. **— L. L.**

Uncommon Moon

Observations made with NASA's Spitzer Space Telescope suggest our Moon's collisional birth is uncommon. A group of astronomers searching for the dusty evidence of large collisions around 30-million-year-old stars estimates similar moon-forming events happen in only 5 to 10 percent of planetary systems.

Astronomers believe our Moon formed when a Mars-sized object collided with Earth 30 to 50 million years after the Sun's formation. The impact flung debris into orbit that eventually coalesced into our nearest neighbor.

A new study examined 400 stars all about 30 million years old, looking for dust created by such collisions. "If there were lots of moons forming, we would have seen dust around lots of stars — but we didn't," says the study's lead author, Nadya Gorlova of the University of Florida, Gainesville. The study appeared November 20 in *The Astrophysical Journal*.

T. A. RECTOR, I. P. DELLANTONIO/NOAO/NSF

COLOSSAL COLLISION. The Moon formed when a Mars-sized object smashed into Earth. A recent study shows such collisions are rare in other planetary systems. This enhanced composite image was taken at Kitt Peak National Observatory.

Gorlova and her colleagues found just one of the systems contains collision-generated dust. The results indicate such catastrophic collisions happen only "once in a Blue Moon." **— L. L.**

QUICK TAKES

STRANGE STARS
Patrick Dufour of the University of Arizona claims several rare white-dwarf stars with carbon atmospheres comprise a new category of star.

MARTIAN MILESTONE
The European Space Agency's Mars Express orbiter completed its 5,000th orbit of the Red Planet November 23, four years after it arrived.

TIDES AND TREMORS
The rise and fall of Earth's ocean tides intensify ultra-slow-motion tremors in Earth's crust, say University of Washington geoscientists.

SOLAR SLINGSHOT
ESA's Cluster satellites show the Sun's coronal mass ejections can slingshot matter in Earth's magnetosphere to speeds exceeding 2.2 million mph (3.6 million km/h).

SLOW TO COOL
Planetary scientists have found Earth and Mars stayed molten for tens of millions of years after they formed.

BALLOON FLOTILLA
NASA will launch 40 high-altitude balloons in 2011 to study radiation in the Van Allen Belts, rings of charged particles surrounding Earth.

WARM AND WARMER
NASA's Solar Radiation and Climate Experiment satellite found regional warming variations on Earth throughout the Sun's 11-year cycle.

SOLAR TWIN
Peruvian astronomers have discovered the most Sun-like star known: HIP 56948, which lies 200 light-years away in the constellation Draco.

SECOND YEAR
On November 9, ESA's Venus Express celebrated its second anniversary at Earth's neighbor. The craft returns images of Venus' atmosphere from an altitude of 31 miles (50 km).

RADIATION INTERFERES
Astronomer Gerrit Verschuur thinks radio emission from the Milky Way will overwhelm the faintest details in the cosmic microwave background.

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NASA/CXC/DURHAM/D. ALEXANDER ET AL.

STAR STACK. To reveal active black holes obscured in dusty, distant galaxies, astronomers combined multiple, faint images into a single clear one.

The great quasar round-up

A multiple-space-telescope survey has unmasked hundreds of black holes obscured within dusty, distant galaxies. As gas spirals into the black holes, they beam brightly with X rays, forming quasars.

The galaxies lie 9 to 11 billion light-years away, dating to the second quarter of cosmic history. Astronomers suspect most, if not all, massive galaxies in the early universe hosted large, active black holes. The quasar round-up confirms their suspicions.

"We had seen the tip of the iceberg before in our search for these objects," says Mark Dickinson of the National Optical Astronomy Observatory in Tucson, Arizona. "Now, we can see the iceberg itself." Dickinson is a co-author of two reports on the quasar discovery that appeared in the November 20 *The Astrophysical Journal*.

Because the galaxies are so dust-rich, astronomers previously saw only a warm infrared glow instead of a quasar's X-ray glare. They now realize the glow traces dust heated from within by the quasar.

A team of astronomers led by Emanuele Daddi of the Commissariat a l'Energie Atomique in France confirmed the existence of the hide-and-seek quasars by combining observations from the Chandra X-ray Observatory and the Spitzer Space Telescope, which sees in infrared. **— D. P.**

Vanguard 1 satellite marks 50 years in space

NASA

STILL ORBITING. Vanguard 1, the first solar-powered satellite, is also the oldest still orbiting Earth. The probe was launched into orbit March 17, 1958, aboard a Vanguard rocket.

The oldest surviving artificial Earth satellite turns 50 on St. Patrick's Day, half a century after the dawn of the Space Age, when Vanguard 1 blasted off March 17, 1958. Thanks to its light weight, the satellite entered a higher-than-usual orbit that promised to be stable for centuries.

Vanguard 1 was the first satellite powered by solar cells. Its small suite of instruments provided unprecedented information on Earth's size, shape, air density, temperature ranges, and the density of micrometeoroids in space. Geophysicists tracking Vanguard 1's orbit learned that Earth is slightly pear-shaped with a slight equatorial bulge, not round.

The satellite was so small in comparison with Sputnik and Sputnik 2 that Soviet Premier Nikita Khrushchev scoffed at what he derided as a "grapefruit satellite." The jibe rebounded, Moscow jokesters reported, when most Russians responded to the metaphor by asking what a grapefruit was.

Scientists named the project Vanguard in 1955 because they hoped it would be the very first element, or vanguard, of human expansion into space. History upset those intentions when both Sputnik and Explorer payloads preceded Vanguard into space.

But fate offers the derelict satellite — which stopped transmitting signals 6 years after its launch — yet another chance to deserve its name. Well before it slips much lower and is threatened with atmospheric immolation, Vanguard 1 may pioneer another space first: becoming the first satellite brought home, for museum display, by a new generation of robotic space vehicles.

Initially launched into an orbit ranging from about 400 to 2,500 miles (650 to 4,000 km), the satellite slowly has lost energy to air drag at perigee (closest approach to Earth). The apogee (farthest point from Earth) of the satellite's orbit has slipped lower by about 2 miles (3 km) per year, while the perigee has dropped at a tenth of that rate. Unless acted on by some outside force, its orbit will continue for hundreds of years.

Commercial space planners are considering offering a prize for the payload's safe retrieval. Nominally, participants would demonstrate technologies for scouring space lanes for dangerous space derelicts and removing them before they are reduced to dangerous clouds of debris by some random space-to-space collision. Emotionally, the idea of grabbing a classic satellite out of the sky is just neat.

Legally, Vanguard 1 isn't space junk. It remains the property of the U.S. government, and quite probably of NASA, which hadn't yet been formed when the satellite was launched. NASA took over the project (and the satellite's operations) later in 1958. Through analogy with maritime law, government property is not subject to automatic salvage rights when abandoned, as is private property at sea, and presumably in space.

One proposal calls for a low-thrust robot to hitchhike into orbit in the ballast section of a communications satellite, then take a year or 2 to match orbits with Vanguard 1, grab it, and wrap it in an inflatable, hollow shell. The shell would increase its air drag 1,000 times. In a few years, the robot would drop Vanguard 1 out of orbit. Just before the satellite's final decay, another small robot could chase it down and install an inflatable thermal shield and a recovery beacon, and nudge it strongly enough to hit an appropriate target — such as sparsely populated Australia. The plan might just work. **— JAMES OBERG**

BRIEFCASE

Mission extended

The European Space Agency voted in November to extend its Ulysses spacecraft's solar mission through March 2009. Since its 1990 launch, Ulysses has orbited the Sun's poles gathering data on solar activity — the first spacecraft to travel so far out of the ecliptic plane.

The craft's high-latitude passes give it a unique perspective for investigating coronal holes and tracking sunspots. Scientists hope Ulysses' 12-month mission extension will shed light on why temperatures differ among coronal holes and if there's a link to the Sun's magnetic polarity. — **L. L.**

Top honors

The Carnegie Foundation for the Advancement of Teaching and the Council for Advancement & Support of Education honored Andrew Fraknoi with the U.S. Professor of the Year Award November 15. Fraknoi, an astronomy instructor at Foothill College in Los Altos Hills, California, was selected from 300 top professors across the United States. — **L. L.**

25 years ago in *Astronomy*

March 1983

In March 1983, for the first time in history, a trip to Mars was technically within reach. *Astronomy*'s cover story discussed the scientific benefits that await us once astronauts land on Mars. "The first Martians" explored the hurdles engineers must overcome before human beings can land on the Red Planet.

Author Bruce Cordell explained potential problems once humans land on Mars, including isolation and temperature extremes. Also, several months are required for a one-way trip to Mars, posing unknown hazards to astronauts. Cordell predicted the first human landing on Mars would be one of the most important events in history.

The United States identified manned Mars exploration as a long-term goal in 2004, and the European Space Agency now hopes to land people on Mars between 2030 and 2035.

March 1998

10 years ago in *Astronomy*

The March 1998 issue of *Astronomy* took a deep look at our universe, bringing it to life with 3-D glasses and 27 spectacular images of moons, planets, and nebulae to view in an extra dimension.

The "3-D blowout" contained two stories about Mars and a photo gallery of the universe, with pages of images viewable in the third dimension.

Inspiration for the issue's 3-D theme came when images captured by Mars Sojourner, the first space exploration rover to reach another planet, began to appear as three-dimensional posters. Sojourner operated for 83 days, 12 times its expected lifetime of 7 days. — **MEGAN McCHAIN**

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QUEST for the

New research gives astronomers a broad-brush view of how galaxies evolve. Now, scientists are filling in the details. /// **BY RICHARD S. ELLIS**

THE RING of bright knots in the center of spiral galaxy NGC 1097 is home to a recent burst of star formation, perhaps triggered by tides caused by its small companion galaxy. ESO

STAR FORMATION is so vigorous in the irregular galaxy IC 10, astronomers characterize it as a starburst. At 1.5 million light-years away, IC 10 is the nearest starburst system. Researchers want to understand how a modest galaxy like this forms stars so readily. LOCAL GROUP SURVEY/NOAO

MORE THAN 10,000 galaxies inhabit the Hubble Ultra Deep Field, a cosmic snapshot at the very limit of the Hubble Space Telescope's vision. In 2003 and 2004, the telescope repeatedly imaged this 3-arcminute-square patch in the constellation Fornax. The result amounts to a million-second exposure. Distant galaxies look ragged, probably a result of frequent collisions.

NASA/ESA/STScI/STEVEN BECKWITH

first galaxies

Imagine traveling back in time for a firsthand view of history. Astronomers come close to having this ability. Light's finite speed means we can witness distant galaxies as they were when the universe was much younger. Astronomers now have two competing and seemingly incompatible scenarios to explain the origin of galaxies. The only way to determine which theory is right is to look back in time.

Looking back

Astronomers slice the universe into time periods defined by the redshift, a displacement in spectral features to longer wavelengths. These light fingerprints indicate how far we're looking back in time: The larger the redshift, the earlier in history we probe. The ultimate goal for extragalactic astronomers is to identify the first galaxies.

At Caltech, my student Dan Stark and I have been using gravitational lensing — the magnification of distant galaxies by foreground galaxy clusters — to obtain a glimpse of the earliest galaxies known. What makes this feat possible are powerful cutting-edge tools: the twin 10-meter Keck telescopes in Hawaii and the Hubble and Spitzer space telescopes. Some of the galaxies we've found lie at redshifts between 8 and 10, corresponding to 500 million years after the Big Bang, or when the universe was only 4 percent of its present age.

Galaxies are the universe's most visible components. In the nearby universe, galaxies come in a bewildering variety of sizes, shapes, and luminosities. Astronomers want to know how these differences arose. What physical processes shape a galaxy's destiny?

In the 1920s, Edwin Hubble at California's Mount Wilson Observatory first recognized the so-called spiral nebulae were not part of the Milky Way, but individual galaxies outside it. But serious campaigns to understand how galaxies reached their present form began in earnest only in the 1960s, when many astronomers began to predict theoretically the colors of various nearby galaxies.

Elliptical galaxies contain mainly ancient red stars, whereas spirals and irregulars contain an abundance of young, short-lived, blue stars. Astronomers concluded that elliptical galaxies must have quickly transformed most of their gas into stars at an early stage. By contrast, spirals and irregulars formed stars continuously but at a more moderate pace.

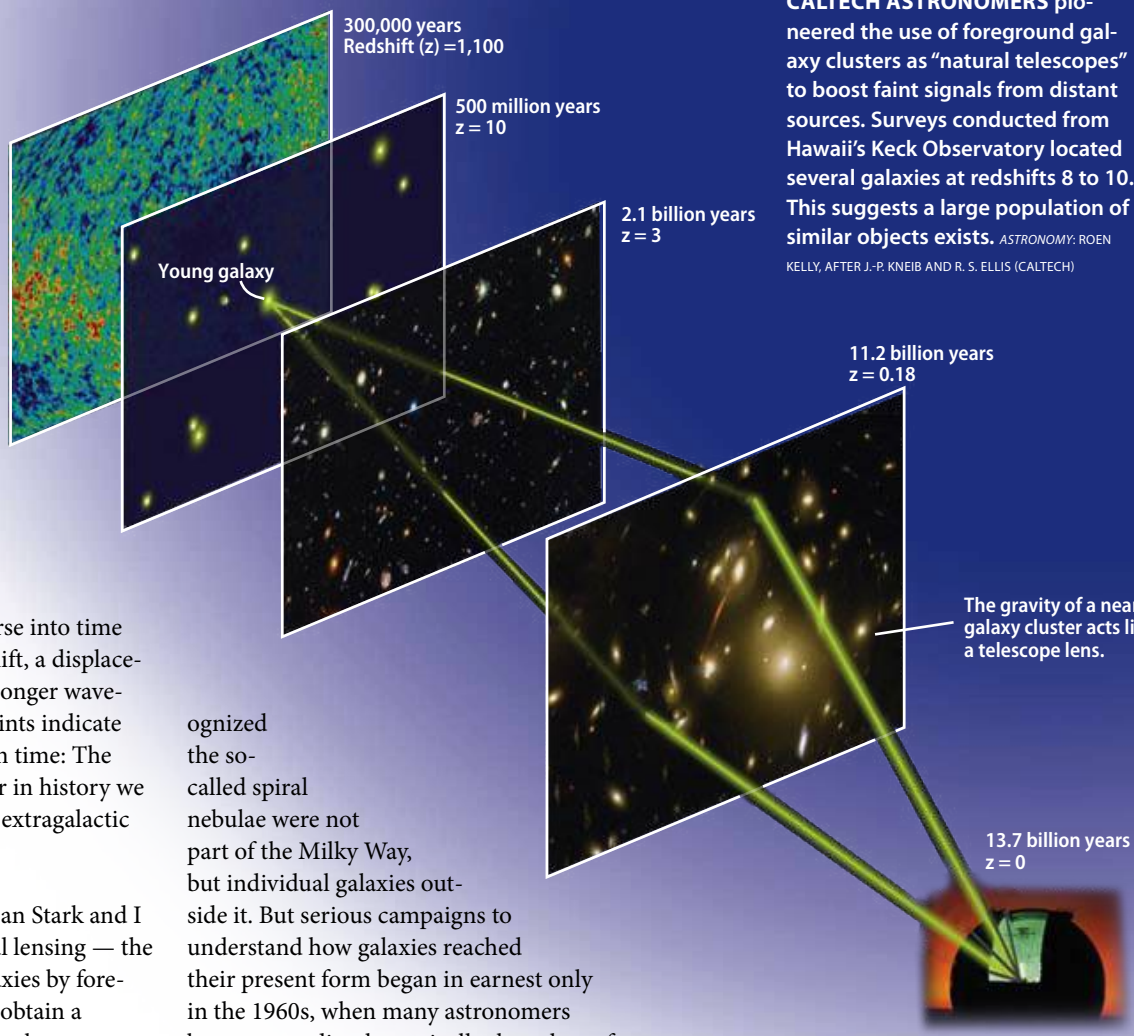
This classical idea for explaining galactic characteristics assumed galaxies were isolated, self-regulated systems. But, relative to their sizes, galaxies now are closer to one another than stars are in the Milky Way. And before the universe reached its current expansion, they were even closer. Therefore, collisions should have occurred frequently.

Moreover, the old theory takes no account of dark matter. In the 1930s, Fritz Zwicky at Caltech discovered dark matter in galaxy clusters, but astronomers didn't detect its presence around individual galaxies until the late 1970s. We now know that most of a galaxy's mass lies outside its visible form in a dark halo. When astronomers incorporated the way gravity congregates dark matter in computer simulations, the influential "cold dark matter" picture of galaxy formation was born.

Dark matter draws together the gas that eventually fuels star formation. What we see as galaxies merely traces dark matter's presence — galaxies are just the icing on the cake. In this view, when gravity brings two dark-matter halos together, their respective galaxies and gas clouds collide. The star-formation rate increases, consuming and exhausting the gas supply. What's left after all this activity is an elliptical galaxy.

The contrast between the classical view and the dark-matter-dominated model could not be starker. In the former, elliptical galaxies are genuinely ancient systems, perhaps the first to have formed, whereas

How cluster lenses magnify distant galaxies



CALTECH ASTRONOMERS pioneered the use of foreground galaxy clusters as "natural telescopes" to boost faint signals from distant sources. Surveys conducted from Hawaii's Keck Observatory located several galaxies at redshifts 8 to 10. This suggests a large population of similar objects exists. *ASTRONOMY*: ROEN KELLY, AFTER J.-P. KNEIB AND R. S. ELLIS (CALTECH)

Richard S. Ellis, *the Steele Professor of Astronomy at the California Institute of Technology in Pasadena, California, is using the Keck, Hubble, and Spitzer telescopes to probe the nature of the earliest galaxies.*

the dark-matter picture sees ellipticals as products of recent mergers. Both may be able to explain the properties of present-day galaxies, but each is based on vastly different evolutionary histories. The only way to determine which is right is to observe what really happened.

New tools

Prior to 1993, astronomers found it difficult to get an accurate census of how distant galaxies differed from their local counterparts. Two powerful observatories changed everything: the Hubble Space Telescope, launched in 1990, and the W. M. Keck Observatory, which commissioned its first 10-meter telescope in 1993.

Fifteen years ago, the most distant normal galaxy astronomers could study lay at a redshift less than 1, which corresponds to a look-back time of some 7 billion years — about halfway back to the Big Bang. With Keck and other ground-based telescopes of comparable power, astronomers now routinely study galaxies to redshift 7, when the universe was less than 1 billion years old.

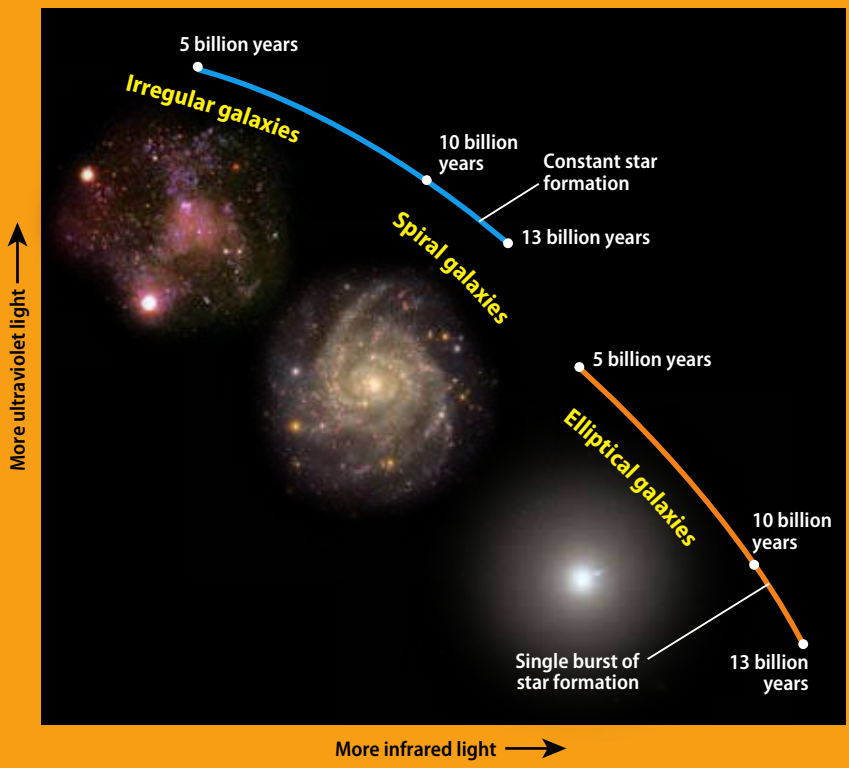
Imagine scanning the crowd in a sports stadium. We easily spot the more exceptional people (say, taller or more colorful). So it is with distant galaxies. Astronomers easily spot the largest or brightest ones, but they can't be sure whether what they're seeing is extraordinary or the norm. So researchers use a variety of techniques to find different galaxy types.

The ability to study distant galaxies at different wavelengths is one of the most important advances in recent times. When

ASTRONOMERS NOW routinely study galaxies to redshift 7, when the universe was less than 1 billion years old.

we look for galaxies at large redshifts using the optical cameras aboard Hubble, we detect star-forming galaxies with an abundance of young blue stars whose ultraviolet signals become redshifted into view. Hubble is then naturally biased to see only those star-forming systems.

Star formation is destiny


5 billion years
Irregular galaxies
10 billion years
Constant star formation
13 billion years
Spiral galaxies
5 billion years
Elliptical galaxies
10 billion years
Single burst of star formation
13 billion years
More ultraviolet light
More infrared light
ASTRONOMY: ROEN KELLY, AFTER C. STRUCK-MARCELL AND B. M. TINSLEY, 1978; SPIRAL GALAXY: NOAA/AURA/NSF; ELLIPTICAL GALAXY: NASA/ESA/HUBBLE HERITAGE (STScI/AURA)

SPIRAL AND IRREGULAR galaxies emit most of their light in ultraviolet and optical wavelengths, but ellipticals shine brightest in the infrared. A single, ancient burst of star formation naturally explains the colors of most ellipticals. Spirals and irregulars, on the other hand, require continuous star formation to explain their colors.

By contrast, an infrared survey using NASA's Spitzer Space Telescope, launched in 2003, can identify a different population of quiescent galaxies, ones that have stopped forming stars. Combining these approaches gives astronomers a more complete inventory. Ground-based telescopes such as Keck provide the crucial redshifts that place each of these galaxies at its correct time in cosmic history.

Revolution rising

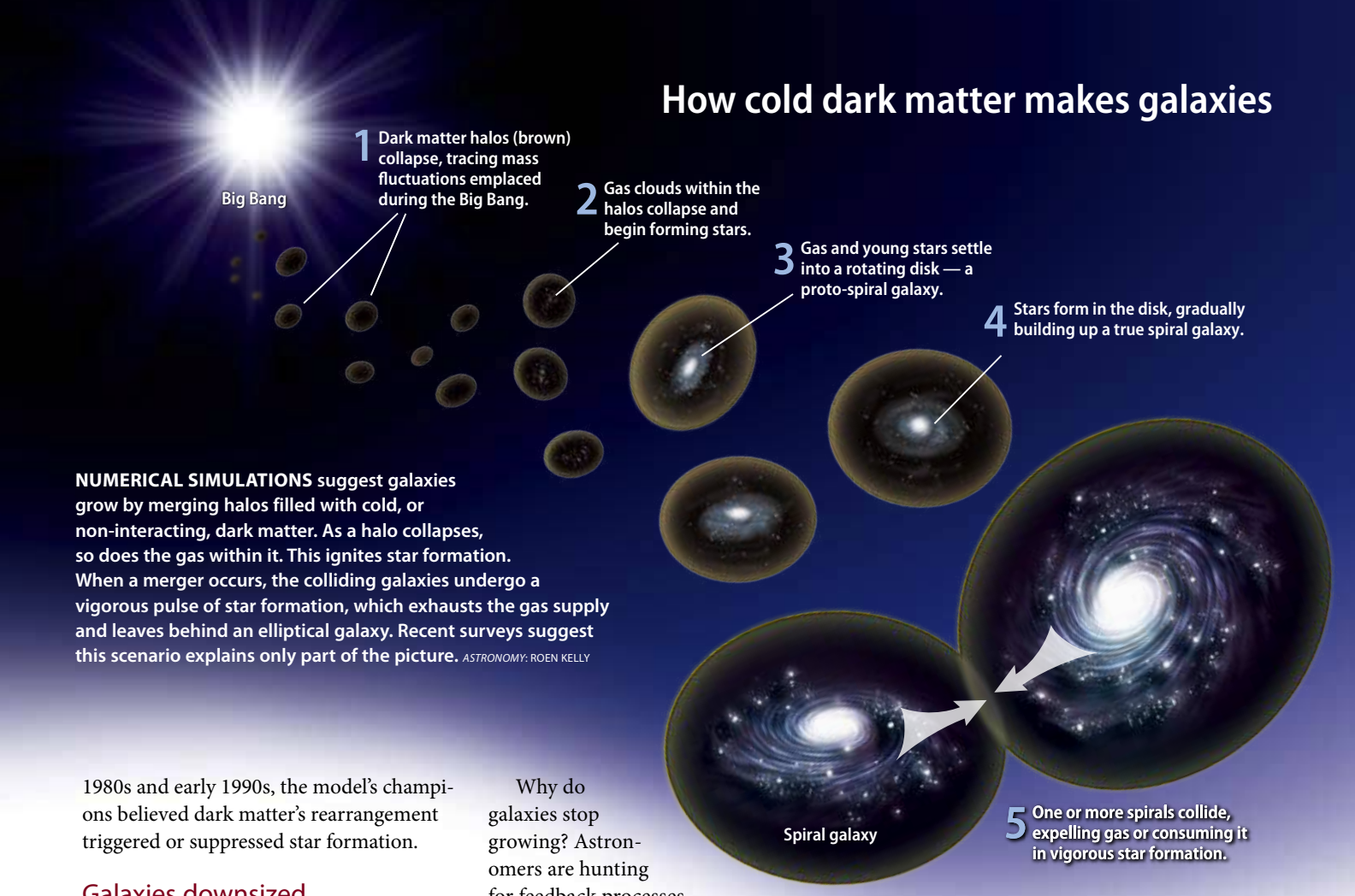
New surveys during the last 5 years are driving an astronomical revolution. First came the famous Hubble Deep and Ultra Deep Fields, where the Hubble Space Telescope observed a single region of the sky to the limits of its abilities. Then, the wider-area Great Observatories Origins Deep Surveys (GOODS) united imaging and spectra from ground-based scopes with deep observations from Spitzer, Hubble, and the Chandra X-ray observatory.

Most recently, the Cosmological Evolution Survey (COSMOS) studied an area 10 times larger than the Full Moon. COSMOS included imaging from most major space-borne telescopes and many ground-based observatories, including the European Southern Observatory's Very Large Telescope in Chile, the Keck and Subaru telescopes in Hawaii, and the Very Large Array in New Mexico.

These massive collaborative projects have yielded unique data for millions of faint galaxies. They've also galvanized global collaborations among scientists and created special "selected areas" — sky fields studied by all major telescopes.

One result of this data explosion is improved knowledge of the universe's star-formation history. According to Andrew Hopkins of Sydney University, who compiled a synthesis of recent results, star formation began at a modest rate early on. It rose to a crescendo between redshifts 2 and 3, and now is in decline.

New research also suggests the dark-matter-dominated scenario for galaxy growth is too simplistic. Yes, dark matter dominates the masses of individual galaxies, and halos can grow through mergers, but the process isn't the primary way a galaxy regulates its star formation. In the


How cold dark matter makes galaxies
Big Bang
1 Dark matter halos (brown) collapse, tracing mass fluctuations emplaced during the Big Bang.
2 Gas clouds within the halos collapse and begin forming stars.
3 Gas and young stars settle into a rotating disk — a proto-spiral galaxy.
4 Stars form in the disk, gradually building up a true spiral galaxy.
Spiral galaxy
5 One or more spirals collide, expelling gas or consuming it in vigorous star formation.

NUMERICAL SIMULATIONS suggest galaxies grow by merging halos filled with cold, or non-interacting, dark matter. As a halo collapses, so does the gas within it. This ignites star formation. When a merger occurs, the colliding galaxies undergo a vigorous pulse of star formation, which exhausts the gas supply and leaves behind an elliptical galaxy. Recent surveys suggest this scenario explains only part of the picture. *ASTRONOMY:* ROEN KELLY

1980s and early 1990s, the model's champions believed dark matter's rearrangement triggered or suppressed star formation.

Galaxies downsized

The main challenge to the dark-matter-driven scenario comes mainly from observations that show many massive galaxies ended their growth and star formation at high redshift, while lower-mass systems continue to add new stars to the present day. This "downsizing," as Len Cowie and his colleagues at the University of Hawaii call it, contradicts a picture in which dark-matter halos grow progressively from smaller units into larger ones. Other physical processes must govern how galaxies convert gas into stars. What can they be?

A 2006 survey led by Caltech graduate student Kevin Bundy, now at the University of Toronto, gives us perhaps the clearest view yet of how downsizing occurred over the past 8 billion years. Bundy and his colleagues tracked the distribution of stellar masses in more than 8,000 galaxies with various star-formation characteristics out to redshift 1.5. Galaxies appear to form young stars until they reach some critical-mass threshold. After that, star formation ends, and the system matures into a red elliptical. Lower-mass galaxies, which make stars at a much slower rate, never reach the cutoff point.

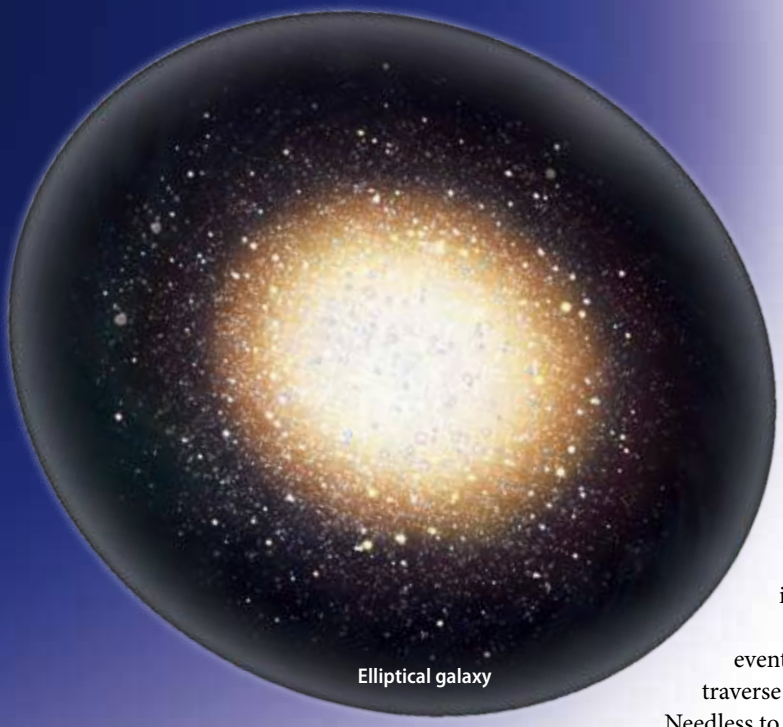
Why do galaxies stop growing? Astronomers are hunting for feedback processes that could inhibit star formation. Perhaps some agent expels gas and shuts down the process. Or maybe gas simply becomes so hot it can't efficiently cool to collapse into stars. Theorists Darren Croton of the University of California, Berkeley, and Richard Bower of Durham University in the United Kingdom suspect the cutoff may be linked to the supermassive black holes found in the centers of most galaxies.

In nearby galaxies, astronomers find a close relationship between a galaxy's mass and the size of its black hole: the bigger the galaxy, the more massive the black hole. Black holes can be dormant, as in our Milky Way, or active, as in galaxies with prominent X-ray emission and energetic jets. Several groups now are using X-ray data from Chandra to test the idea that black holes govern star formation in a galaxy. They're attempting to explain downsizing trends by determining which galaxies have active black holes at various times.

When did spirals spiral?

Nearby galaxies show different dynamical properties. Our Milky Way, a spiral galaxy, contains a rotating stellar disk. An elliptical galaxy, on the other hand, is basically a ball of stars, each of which follows a random orbit. To understand a galaxy's internal dynamics, we need detailed spectra from different parts of the galaxy. That's quite a challenge at great distances. A galaxy at redshift 2, for example, is only 1" to 2" across. From a typical ground-based observatory, Earth's atmosphere would blur any rotation pattern.

Fortunately, several major telescopes boast another innovation, called adaptive optics, that overcomes this difficulty. With a perfect correction, a 10m telescope could attain a resolution of 0.05" at near-infrared wavelengths. This corresponds to details as small as 1,000 light-years for a galaxy at redshift 2! While adaptive-optics systems don't usually perform this well in practice, groups led by Reinhard Genzel (Max Planck Institute for Extraterrestrial Physics in Munich) and Chuck Steidel (Caltech) have achieved substantial resolution gains. Their results suggest that many distant galaxies have yet to reach the dynamical maturity we see locally.



6 The merger's end product is an elliptical galaxy.

Astronomers hope to uncover an evolutionary trend as more teams use the remarkable power of adaptive optics. Among other things, we'd like to know when the rotating disks we see in all present-day spirals became established.

Final frontier

For astronomers interested in galaxy evolution, baby galaxies — those that formed only a few hundred million years after the Big Bang — mark the final frontier. The search for the first galaxies, which astronomers believe formed when the universe was less than 5 percent of its present age, now drives the design of new telescopes.

Some 300,000 years after the Big Bang, hydrogen gas clouds formed. Gravity from dark-matter clumps gathered and compressed the clouds, which collapsed and formed the first stars. These pristine systems contained only the nuclei of the simplest atoms, hydrogen and helium, forged in the Big Bang.

Theorists like Tom Abel at Stanford University believe these first stars were short-lived and massive. They shone briefly at redshifts of 20 to 50, long before the wholesale formation of small galaxies at redshifts 10 to 20. This first stellar generation may have been numerous and energetic, so much so that their ultraviolet light escaped and affected cold hydrogen in deep space. This radiation stripped electrons from hydrogen atoms, ionizing them. Only after this event could visible light traverse intergalactic space. Needless to say, observing when this landmark event occurred, and characterizing the sources responsible for it, excites astronomers.

For galaxies at redshifts beyond 7 — a distance corresponding to 900 million years or less after the Big Bang — cosmic expansion shifts most of their light into infrared wavelengths. This is a particularly challenging region of the spectrum for ground-based observations. Ultimately, future facilities such as NASA's James Webb Space Telescope (JWST) — a 6.5-meter successor to Hubble — will reach to much greater depths. The observatory, slated for launch in 2013, is optimized for infrared work.

THE FAINT SOURCES found through gravitational lensing are up to 100 times smaller than the Milky Way.

A few years later, if all goes according to plan, a new ground-based observatory called the Thirty Meter Telescope (TMT) will complement JWST. With a mirror 3 times the size of the Keck telescopes and coupled with adaptive optics, TMT will provide details on physically small sources.

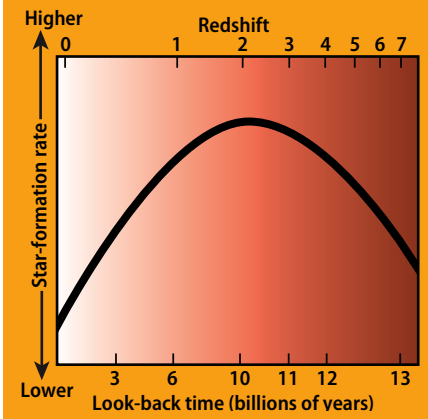
The faint sources Dan Stark and I found using gravitational lensing are, indeed, physically small — only 1,000 light-years across. That's 50 to 100 times smaller than the Milky Way. There seem to be a lot of them, and their collective energy output could represent a significant fraction of the energy needed for cosmic ionization.

We're working now to verify this, but we've almost reached the limits of current astronomical facilities. More detailed studies of the most remote galaxies currently known may simply have to wait for new facilities like JWST and TMT.

Hubble, Spitzer, and Keck enable us to see how galaxies developed from small, immature systems into the majestic forms Edwin Hubble classified in the 1920s. The theory underpinning galaxy growth has made great strides, too, even if the details of how galaxies regulate their star formation remain unclear. We now look to the final frontier, peering back to an era before galaxies formed.

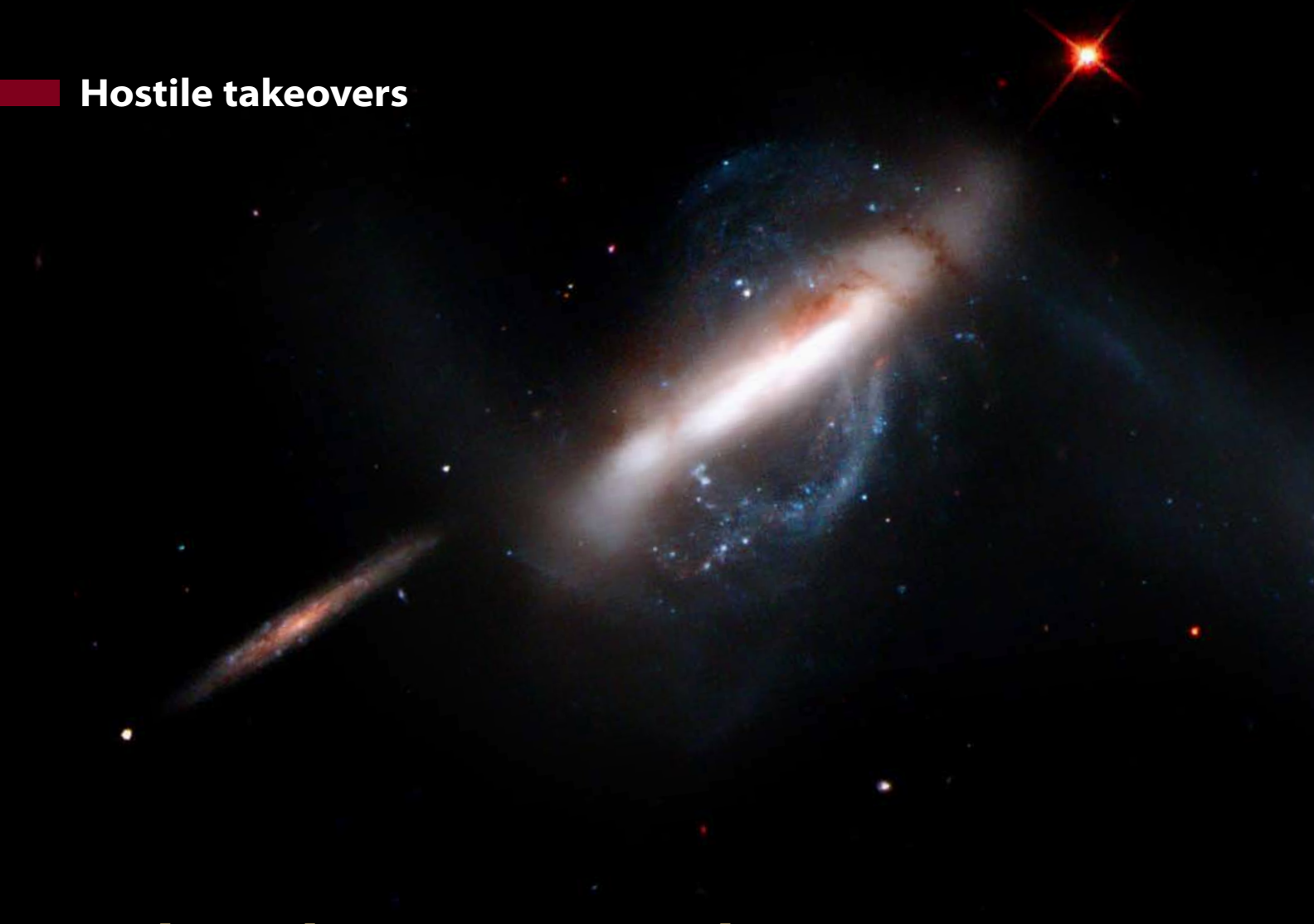
Edwin Hubble understood both our motivations and our challenges. "At the last dim horizon," he said, "we search among ghostly errors of observations for landmarks that are scarcely more substantial. The search will continue. The urge is older than history. It is not satisfied and it will not be oppressed." A

Star formation through time



NEW RESEARCH gives astronomers a census of the universe's star-formation history. Activity peaked between 10 and 11 billion years ago. The universe now forms stars at 10 percent of the rate it did 7 billion years ago. *ASTRONOMY:* ROEN KELLY, AFTER A. M. HOPKINS AND J. F. BEACOM, 2006

WEB EXTRA Learn more about Richard Ellis' work on the most distant galaxies at www.Astronomy.com/toc.



What happens when GALAXIES COLLIDE?

Simulations show a cycle of mergers, starbursts, and black holes built the universe's grandest constructions: giant elliptical galaxies. ///

BY STEVE NADIS

IN THE MERGING SPIRAL GALAXIES NGC 3808 (right) and NGC 3808A, gravitational interactions trigger vigorous star formation. Such collisions between spirals drive the formation of large elliptical galaxies. NASA/ESA/HUBBLE HERITAGE TEAM

With a click of a computer mouse, astrophysicist Volker Springel sends two spiral galaxies hurtling into each other. As the galaxies merge, gas compresses to form new stars. Gravitational tides warp the merging mass, drawing out long, wispy tails of gas and stars like pulled taffy. A massive central black hole grows exponentially, cannibalizing gas from the merging spirals. The black hole emits a glaring X-ray glow as gas falls into it at near light-speed.

Suddenly, the black hole seems to turn suicidal: Its intense energy blasts the surrounding gas clear out of the galaxy. This extinguishes its own growth as well as active star formation farther from the core.

"My jaw dropped," recalls Springel, upon seeing the mighty wind blowing outward from his simulated black hole. Watching the simulation in his office at the Max Planck Institute for Astrophysics in Garching, Germany, Springel realized that when a black hole is done eating, it doesn't just leave the kitchen — it blows away the whole pantry.

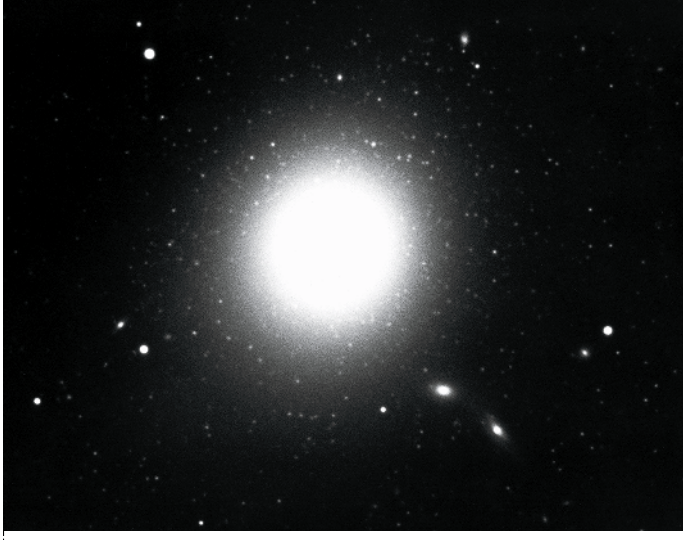
Steve Nadis, *a frequent contributor to* Astronomy, *writes about science at his home in Cambridge, Massachusetts.*

Theorists had speculated about "feedbacks" that might cut off a black hole's fuel supply, but nobody knew what such an outflow might look like. "There's a big difference between a zigzag line on a graph and seeing a color, three-dimensional computer visualization," Springel says.

The merger "movie" caused quite a stir when Springel later premiered it at a scientific meeting in Garching. But not even he appreciated its full significance at the time. The simulations have raised an intriguing possibility: The explosive growth and sudden crash of black holes may be part of a much larger process in galaxy evolution.

The complete "cosmic cycle" includes a pulse of rapid star formation (a starburst), black-hole growth, and the formation of an ultraluminous galactic core — a quasar. Finally, the quasar dims, star formation slows to a crawl, and the merged spirals slowly evolve into a single, large elliptical galaxy.

If the simulations are accurate, the multi-billion-year cosmic cycle starts with a single event: the merger of gas-rich spiral galaxies. This scenario ties together different aspects of galaxy evolution into a single framework. It could also explain why most galaxies in the universe are either spirals or ellipticals, with little in between.



THE GIANT ELLIPTICAL GALAXY M87 harbors a central black hole some 3 billion times the Sun's mass. NOAO/AURA/NSF

Astronomers think mergers among smaller gas-rich spiral galaxies, like M101 (above), formed most elliptical galaxies. NOAO/AURA/NSF

It's only gravity

Springer's collaborators in the simulation studies include Lars Hernquist and others at the Harvard-Smithsonian Center for Astrophysics (CfA), as well as Tiziana Di Matteo of Carnegie Mellon University in Pittsburgh. The team is the first to incorporate mergers, starbursts, black holes, and quasars into a seamless simulation of galactic evolution.

Pioneering merger simulations in the 1970s by MIT mathematician Alar Toomre and his brother Juri (the latter now at the University of Colorado in Boulder) hinted at some of the same conclusions as more recent efforts. The Toomres' galactic mergers included the motions of a mere 200 bits of matter, in contrast to the billions of "test particles" in modern numerical models.

But even in the early models, mergers give rise to the misshapen galaxies resembling those observed in nature — complete with arches, tails, filaments, and other strange appendages. Theoreticians devised a variety of explanations for the shapes.

"They were weird, they looked like they were made by biology," Alar Toomre recalls. "In the end, it turned out to be just gravity."

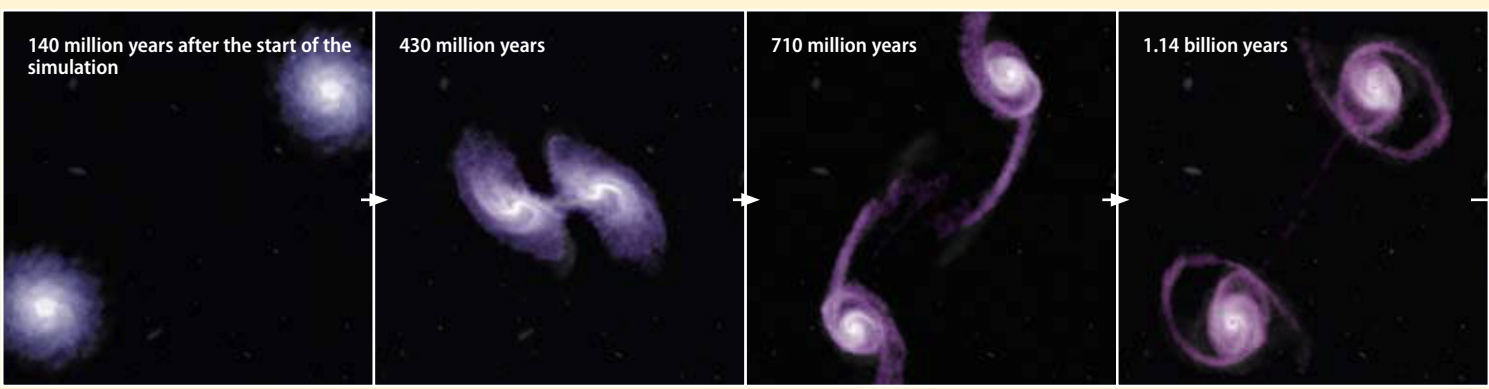
To visualize the results, the Toomres drew all 23 figures in their landmark 1972 paper by hand, using India ink and drafting instruments. Since then, simulations have advanced tremendously as computing power has grown. A cluster of more than 300 parallel processors — soon to increase to 500 — now churns away in the basement of Hernquist's building. Meanwhile, team member Di Matteo conducts merger simulations at the Pittsburgh Supercomputing Center using a Cray XT3 machine with the processing capacity of 30,000 PCs.

A new picture

At first glance, it's impressive to witness the spiral-merger visualizations, rendered

Galactic mergers in cyberspace

These panels depict milestones during the merger of two spiral galaxies over 4 billion years. The process culminates with the birth of an elliptical galaxy. The computer model that produced these images combined simulations of the behavior of both stars (white) and interstellar gas (blue).



SOON AFTER the simulation begins, two identical spiral galaxies approach each other. Each galaxy begins to feel the other's gravitational tug, even at a distance of hundreds of light-years.

THE GALAXIES MEET and pass through each other without physical contact, reflecting the vast empty space between individual stars. Gravitational attraction creates tidal forces that distort the galaxies' shapes. Gas flows into the galaxies' cores, fueling starbursts.

AFTER THE FIRST encounter, the galaxies lose momentum and slow down. Mutual attraction draws wispy "tidal tails" of gas and stars from each galaxy. Star formation in the galactic cores quiets down.

THE GALAXIES SLOW to a stop at a distance between 150 and 300 light-years and start to come together again. The tidal tails merge to form a cool, gaseous "bridge" between the galaxies.

using state-of-the-art 3-D graphics software instead of pen and ink. With their ghostly dance of billions of gas particles, the animations seem more like Hollywood special effects than scientific data.

Seeing, however, is not necessarily believing, warns astronomer Mitchell Begelman of U.C. Boulder. "Although the movies look real and provide a reasonable answer, it may not be the right answer."

Nevertheless, Begelman concedes, the simulations do support the general picture astrophysicists have been converging

> "THEY WERE WEIRD, they looked like they were made by biology." — Alar Toomre

toward — a twisted tale kicked off by galactic mergers. Alar Toomre also suspects the new simulations seem to be on the right track: "There's no way the whole thing could be wrong."

The simulations suggest that galaxies grow through mergers. Gravitational forces unleashed by the merger channel gas into the galactic core, triggering starbursts. The presence of such large quantities of gas also enables the galaxy's central black hole to grow rapidly. During the ensuing feeding frenzy, the black hole's swirling gas halo heats up and emits vast amounts of energy, eventually becoming a quasar. With formation of the quasar, the galaxy's energy output is nearly at its peak.

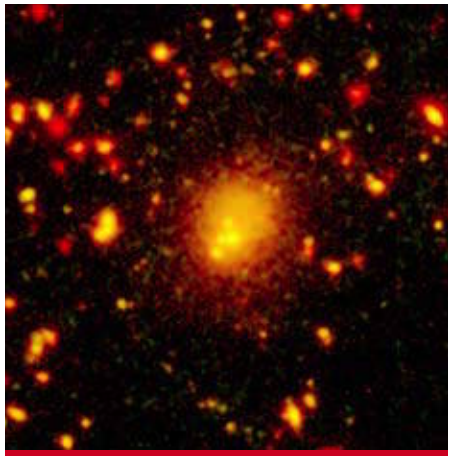
But when the black hole's energy output exceeds a certain threshold, it spews a jet of superheated plasma into its halo. The gas heats so quickly that gravity cannot prevent it from bursting out of the galaxy altogether. Black-hole growth, star formation, and the quasar's energy output wilt when deprived of fuel. The black hole's growth spurt created a negative feedback that ultimately shut down the whole system.

"I worked on galaxy formation for a long time without caring about black holes," says Springel. "We now see they're connected in intimate ways."

Philip Hopkins, a graduate student in Hernquist's group, pushes the concept even further. He suspects supermassive black holes may be the "prime movers" behind galaxy evolution, "responsible for much of what goes on in shaping galaxies."

Gas-rich solutions

Today's simulations include the behavior of gas. This requires a lot of computing horsepower, because gas behavior in galaxies is far more difficult to model than simple gravitational attraction. But including gas dynamics has yielded more realistic portraits of galaxy mergers.

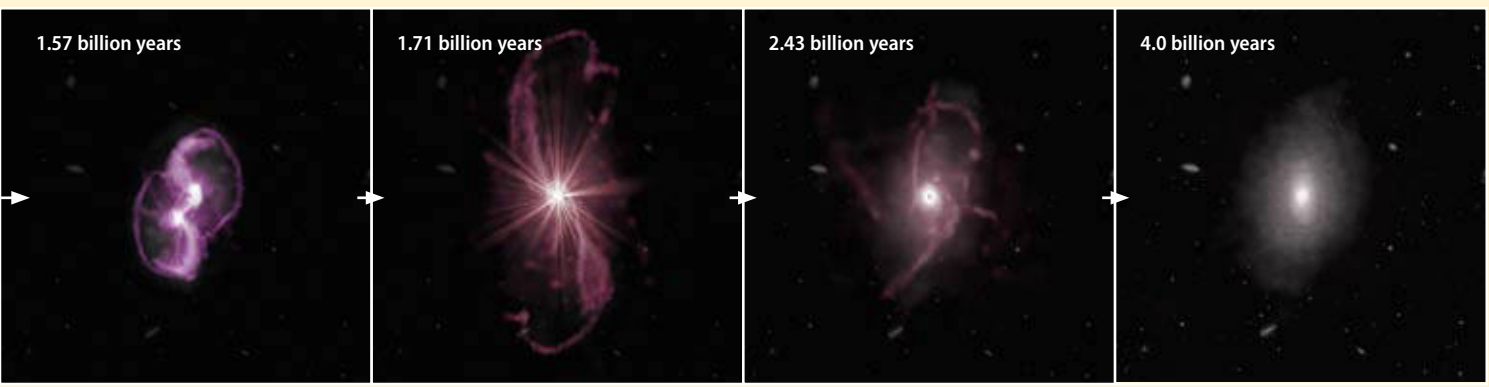


NASA/JPL-CALTECH/KENNETH RINES (CfA)

GALAXY MERGERS aren't limited to two partners. Astronomers discovered a 4-way galactic crack-up about 5 billion light-years from Earth. They may evolve into a single supergalaxy with a mass 5 times the Milky Way's.

"The first generation of merger simulations produced objects that looked like elliptical galaxies, but the stars were distributed incorrectly," Hopkins says. Their latest efforts do better. "It's not just something that vaguely looks like an elliptical galaxy," Hopkins explains. "The computed values for the stars' orbits, velocities, and distributions are consistent with observations of real galaxies."

Gas-savvy simulations have produced intriguing results. In 2005, Di Matteo, Springel, and Hernquist merged two spiral galaxies in a simulation that included both



LARS HERNQUIST AND THOMAS J. COX (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS)/ VOLKER SPRINGEL (MAX PLANCK INSTITUTE FOR ASTROPHYSICS)

GALAXIES MERGE into a single mass. Star formation reignites as gas flows into the galactic cores. By the merger's conclusion, repeated starbursts have consumed 90 percent of the spirals' available gas.

FEEDING ON GAS, the central black hole in the merged galaxy grows exponentially. The black hole emits a vast amount of energy, which dissipates the surrounding gas. As a result, the black hole stops growing and star formation ceases.

THE MERGED GALAXY still contains tidal tendrils of gas and stars created by the forces unleashed in the merger. Only a trickle of star formation remains.

THE TIDAL STRUCTURES relax over time, completing the merger of two spiral galaxies into a single, giant elliptical with a central black hole. The disk-like structure of the original spiral galaxies is virtually gone.

HOT YOUNG STARS GLOW in a burst of star formation in the galaxy IC 10. Starbursts are common during the merger of gas-rich spiral galaxies. UCB/NASA/KECK OBSERVATORY

the growth of the central black hole and the feedback between the black hole and the rest of the galaxy. This revealed that the ultra-bright quasar phase is short-lived, lasting only about 10 million years.

This finding may explain why quasars are now so rare: They peaked back when the universe was a few billion years old and mergers were more common.

Mass puzzle

Merger simulations have also shed light on the curious "mass correlation" astronomers observe in real galaxies. Black holes at the centers of galaxies consistently contain about 0.2 percent of the mass of either the central bulge in a spiral galaxy or the entire galaxy in an elliptical.

Some astronomers think the correlation exists because black holes and their host galaxies grow in lockstep. The black hole and the galaxy gain mass at about the same rate. But when the black hole develops a strong galactic outflow, it sweeps the core clean of gas. Neither the black hole nor the galaxy can grow larger at this point.

Theoretical astrophysicist Nick Gnedin of Fermilab in Batavia, Illinois, finds this explanation slightly wanting. Black holes are small compared to their galaxies, yet somehow their rates of growth continue at the same pace. This requires a fine balance.

"How is the feedback coordinated so that the galaxy supplies the black hole with just the right amount of gas and the black hole throws out just the right amount of energy?" Gnedin asks.

Computer models can't answer this question now because they lack all the complexities of the process. For example, models don't account for how gas flows into a black hole and how, in turn, the surrounding gas absorbs radiation emitted by the black hole.

Despite the uncertainties, theorists try to make the most reasonable assumptions they can, acknowledging that their scenarios remain unproven. "Right now we have a story without a detailed mechanism," Hernquist says.

Observational clues

Theorists can go only so far without testing their ideas against hard data. Soon after reading the Toomres' 1972 paper, François Schweizer of the Carnegie Institution of Washington began accumulating observational evidence that mergers are common in the history of the universe.

At first, many astronomers ignored Schweizer's findings because they clashed with the conventional view of galaxies as "island universes" evolving in isolation from each other. It took years before people acknowledged elliptical galaxies might be the product of mergers.

Thanks, in part, to observational clues gathered since the 1970s, the fundamental role of mergers in galaxy evolution has gained broad acceptance. "Mergers were once considered an exotic phenomenon, but we now believe that's how all structure grows," Di Matteo explains. "In the same way, black holes were once considered exotic but are now considered fundamental constituents of galaxies, just like stars."

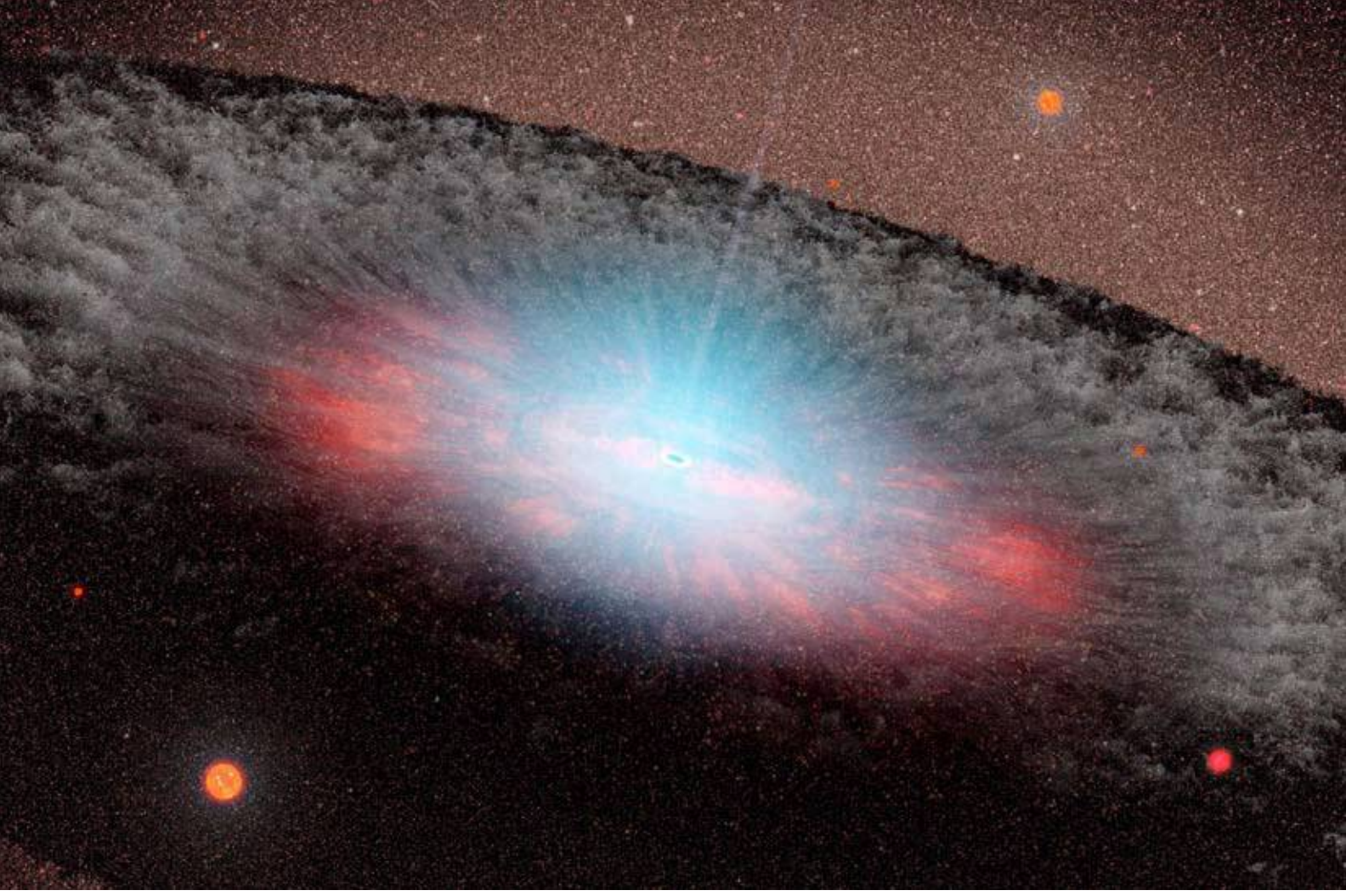
Early support for the merger paradigm came from the Infrared Astronomical Satellite (IRAS), launched in 1983. IRAS found galaxies 100 times more luminous in infrared than in visible light — a clear sign of active star formation.

"When two galaxies slam together, the gas gets enormously compressed," Schweizer explains, "and in the densest part, millions of stars form." Moreover, roughly 80 percent of these galaxies had tails, unmistakable evidence of past mergers.

"In the nearby universe, every luminous quasar is part of a merging or colliding system," he adds. "There's no reason to believe distant quasars are any different." Indeed, observations with the Subaru Telescope in Hawaii and the Very Large Telescope in

ROBERT GENDLER

A "RELATIVISTIC JET" of electrons and other subatomic particles streams from the elliptical galaxy M87. Amateur astronomer Robert Gendler captured the ultraluminous jet with a 12.5-inch telescope and multiple images stacked for a combined 13-hour exposure.



AFTER SPIRALS MERGE, gas migrates toward the center to feed a supermassive black hole. The blue in this artist's concept indicates radiation blazing from the "donut" of gas and dust girding the black hole. NASA/JPL-CALTECH

Chile have revealed that large spiral galaxies existed some 10 billion years ago during the epoch of peak quasar formation.

Additional insights on mergers have come from an ultraviolet survey of more than 800 elliptical galaxies using NASA's Galaxy Evolution Explorer (GALEX). A team led by Sukyoung Yi of Yonsei University in South Korea found that star formation drops off sharply as galaxies and their central black holes increase in size.

The GALEX study points to the same scenario as the merger models: Once the black hole exceeds a critical mass relative to the galaxy, the energy it injects into the rest of the galaxy — either through jets or some other heating mechanism — shuts off star formation and black-hole growth.

The physics makes sense, but it still seems surprising that a relatively small object like a black hole, with less than 1 percent of the galaxy's total mass, controls star formation throughout the galaxy's lifetime. "It's just like my small brain telling me what to do for the rest of my life," Yi jokes.

More data on the way

Models advance in step with new observations — and vice versa. Giovanni Fazio, a lead scientist with the Spitzer Space Telescope project, works closely with his colleague Hernquist at the CfA. "I might show Lars a picture of colliding galaxies and ask,

THE FUNDAMENTAL role of mergers in galaxy evolution has gained broad acceptance.

'Have you ever come across this shape in your simulations? If so, tell us the vital parameters — the mass of the colliding galaxies, the angle of impact, impact velocity, and so forth,'" Fazio says.

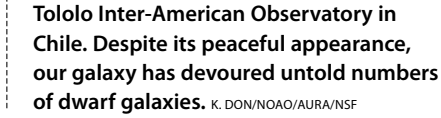
Such collaborations between observers and theorists will be formalized in a 4-year, $3 million project at the CfA to develop a comprehensive theory of galaxy formation. Another goal of the project is to improve the resolution of computer simulations so astronomers can make meaningful comparisons to observed galaxy mergers.

"Although the observational data is ahead of the simulations right now, the simulations are coming up fast," Fazio says. "It's been a beautiful collaboration so far, and it'll only get better."

Observers still have the edge when it comes to details. They can spend a year or more examining a single object. But simulations offer a valuable perspective.

"Observing one or two objects cannot possibly compete with the view cosmological simulations afford," Schweizer says. "That global view, moreover, keeps getting better. It can inspire and stimulate observers, guiding us where to look next." A

WEB EXTRA Watch a simulation of two spiral galaxies merging at www.Astronomy.com/toc.



THE MILKY WAY climbs majestically above the 4-meter telescope at Cerro Tololo Inter-American Observatory in Chile. Despite its peaceful appearance, our galaxy has devoured untold numbers of dwarf galaxies. K. DON/NOAO/AURA/NSF

How the Milky Way devours its neighbors

Our galaxy's current eminence owes much to a past — and present — spent cannibalizing dwarf galaxies. ///

BY RAY JAYAWARDHANA

On a clear, moonless night, the Milky Way appears the very picture of serenity. Yet its gentle glow masks a life of turmoil. Episodes of violence, plunder, and cannibalism pervade astronomers' emerging picture of our galaxy's history.

Unraveling this story, with the help of painstaking observations and sophisticated computer simulations, could shed light on how the Milky Way acquired its form. It could also help astronomers understand galaxy evolution in general.

The classical view of the galaxy's origin, proposed more than 4 decades ago, starts with a single large gas cloud that collapsed when the universe was in its infancy. In 1978, however, Leonard Searle and Robert Zinn, then at the Carnegie Observatories in Pasadena, introduced a new twist. They suggested some globular clusters — dense knots of hundreds of thousands of stars residing in the galactic halo — joined the Milky Way after its central regions and disk already had taken shape. Ever since, various astronomers have argued that certain globular clusters are stolen goods, wrested away from other, smaller galaxies as they merged with the Milky Way.

Clusters orbiting the galactic center "backward" (compared with the orbits of the Sun and most other stars) are among the most likely interlopers. Many researchers think Omega Centauri (NGC 5139), the most massive globular known and one that's particularly deficient in heavy elements, could be the nucleus of a disrupted dwarf galaxy.

This more chaotic picture agrees better with today's theoretical ideas about how galaxies grew from the universe's smooth beginnings. The favored model goes by the name "cold dark matter" (CDM). This theory assumes dark matter — the still-mysterious stuff whose gravity dominates over normal matter — consists of slow-moving (hence "cold") particles.

From the bottom up

The CDM scenario, explored in numerous theoretical calculations and simulations, suggests structure formed from the bottom

OMEGA CENTAURI (NGC 5139) — the Milky Way's biggest and brightest globular cluster — may be the nucleus of a dwarf galaxy captured long ago by the Milky Way. DANIEL PHILLIPS

up. Large galaxies grew from the mergers of smaller clumps, and those galaxies later came together to make clusters and, in turn, superclusters. One challenge for the CDM model is that it predicts many more dwarf galaxies in our cosmic neighborhood than astronomers have found so far.

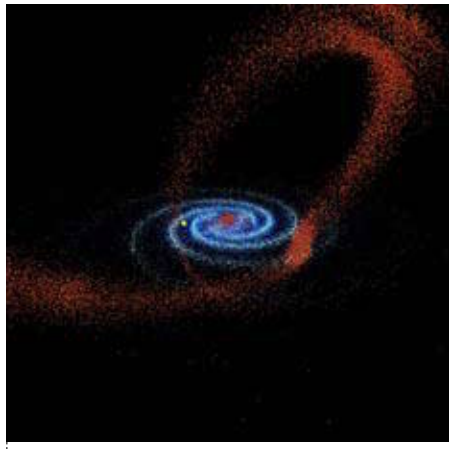
It could be that the Milky Way and other large galaxies, like the nearby Andromeda Galaxy (M31), already have gobbled up most of their smaller brethren or distorted them so much they are difficult to spot even in our own backyard. A massive galaxy exerts powerful tidal forces because the gravitational pull acting on the near side of a neighbor significantly exceeds that acting on the far side. These forces overwhelm the gravity that binds a dwarf galaxy together and rip it apart. The unfortunate galaxy's gas and stars get pulled into long trails or streams that eventually disperse. Once the "loot" mixes in with the big galaxy's contents, tracing its origin proves far from easy.

The vast majority of mergers that built our galaxy probably happened early in its history. But the Milky Way continues to destroy and swallow its remaining neighbors.

Big news from small galaxies

The Magellanic Stream has often been held up as the poster child of an ongoing merger. The Stream consists of gas stripped from two irregular satellite galaxies well known to Southern Hemisphere observers, the Large and Small Magellanic Clouds. First identified more than 30 years ago, the Stream stretches some 600,000 light-years. It features arms that both lead and follow the Clouds' orbits around our galaxy.

Some models suggest the Milky Way created these filaments. However, MIT astronomer Nitya Kallivayalil and her colleagues recently found that the Clouds are moving unexpectedly fast. Unless our galaxy has far more mass than we think, the Clouds may be on their first pass — and tides alone likely could not produce the Stream.



THE SAGITTARIUS DWARF GALAXY appears as a distorted stream of reddish dots surrounding the bluish spiral arms of the Milky Way. This simulation best models data derived from the 2MASS project. DAVID LAW/UNIVERSITY OF VIRGINIA

The Milky Way also seems to be disrupting other Local Group dwarfs. University of Virginia astronomer Steven Majewski leads one of several groups that have discovered tidal debris from several of these dwarfs, including those in Carina, Leo I and II, Ursa Minor, and Sculptor.

Perhaps the most dramatic case of a cannibalized Milky Way satellite is the Sagittarius dwarf galaxy. Rodrigo Ibata, then a graduate student at Cambridge University, found it almost by accident.

In 1994, he was studying the motions and chemical compositions of stars in our galaxy's bulge. While collecting spectra of his sample stars at the Anglo-Australian Telescope in Australia, Ibata noticed a few of the reddest stars had velocities different from all the others. Even stranger, these stars appeared to be moving together. On the next couple of nights, he took spectra of more red stars — they all shared the same unusual motion.

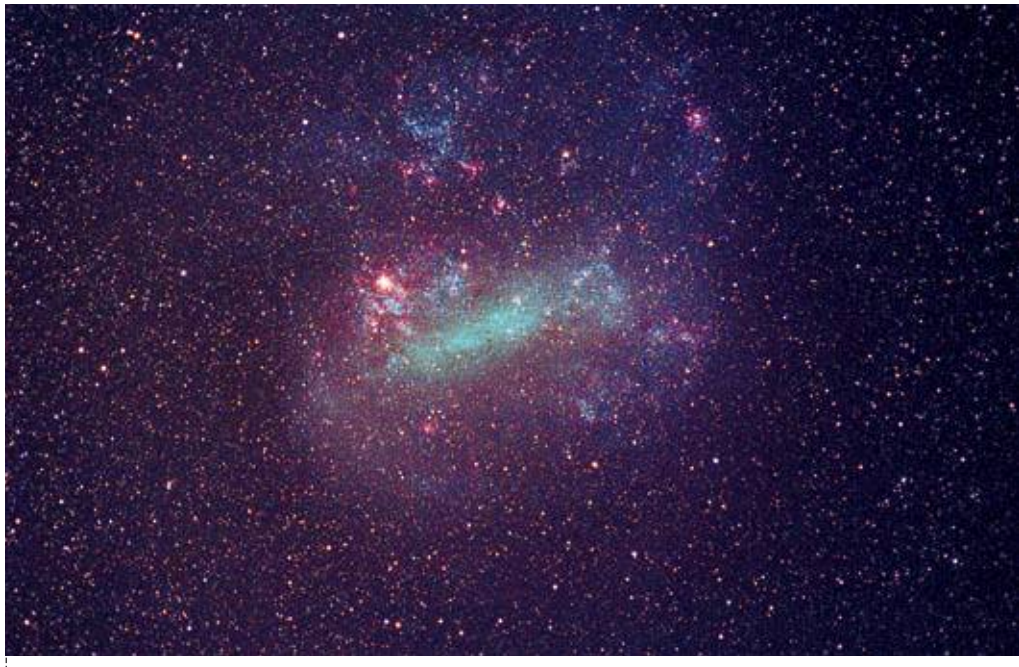
When he returned to Cambridge, Ibata and his colleagues scanned archival photographic plates of that region of sky, then plotted the positions of red stars similar in brightness to those he had found with peculiar velocities. This exercise revealed the contours of a hitherto unknown galaxy. It lies roughly perpendicular to the Milky Way's disk and about 100,000 light-years away, on the far side of the galactic center.

Contributing editor **Ray Jayawardhana** *is the Canada Research Chair in Observational Astrophysics at the University of Toronto. He teaches introductory astronomy to 1,000 non-science majors each term and studies the origins of stars, brown dwarfs, and planets.*

It had been hiding behind the Milky Way's thick veil of stars and dust. What's more, the newly found dwarf spheroidal galaxy, named Sagittarius after the constellation that contains its center, has a rather contorted appearance — clear evidence of bullying by its massive neighbor.

During the past decade, astronomers have attempted to chart the Sagittarius dwarf's full extent. Recent maps show its debris scattered in a giant arc that wraps around the Milky Way. Ibata's team and others argue that several globular clusters previously thought to belong to our galaxy actually came from the Sagittarius dwarf. Other stolen clusters and individual stars may exist, but they're already so well mixed in with the Milky Way's own that astronomers can't trace their origins.

The surprise discovery of the Sagittarius dwarf raised the possibility others like it may lurk undetected. Astronomers imagined spaghetti-like strands crisscrossing the Milky Way, each filament retaining a faint memory of the path taken by its long-since-destroyed parent galaxy or globular cluster. Scientists tried to identify streams of stars with peculiar motions and chemical abundance patterns, which might betray their alien origins.



THE LARGE MAGELLANIC CLOUD provides a major portion of the Magellanic Stream, a 600,000-light-year-long concentration of gas perhaps stripped by the Milky Way from this irregular satellite galaxy and its neighbor, the Small Magellanic Cloud. ANDREAS B'KER AND AXEL MARTIN

The tides turn to Sloan

For researchers in pursuit of these elusive fossils, the Sloan Digital Sky Survey has turned out to be a treasure trove. Initiated in 2000, the survey covers more than a quarter of the sky in several optical bands.

Michael Odenkirchen and Eva Grebel, then at the Max Planck Institute for Astronomy in Germany, and their colleagues quickly discovered two tidal trails. The trails emerge from a sparse and remote globular cluster cataloged as Palomar 5. One of these trails has now been traced across more than 20° of sky, or some 25,000 light-years.

Scientists think Palomar 5 lost much of the observed debris within the past 2 billion years. Simulations suggest this cluster will break apart completely the next time it crosses the Milky Way's disk, just 100 million years from now. Other researchers have since identified an even larger debris arc associated with the globular cluster NGC 5466.

In 2003, Heidi Jo Newberg of Rensselaer Polytechnic Institute in Troy, New York, Brian Yanny of Fermilab outside Chicago, and their colleagues reported the discovery of a "ring" of stars beyond the visible edge of the Milky Way's disk. Stars in this "Monoceros Stream" (so dubbed because its center lies toward that constellation) stood out in the Sloan data because they have unusual colors.

The colors arise from the stars' paucity of heavy elements. Some scientists think the stream originates from a dwarf galaxy in the neighboring constellation, Canis Major, that's being torn apart by the Milky Way.

Just 2 years ago, Mario Juric of Princeton University and his colleagues found a remarkable enhancement in stellar density toward the constellation Virgo. The structure turned up in a 3-D map of about 48 million stars the team made from Sloan survey data. At an estimated distance of 30,000 light-years, it lies well within the Milky Way's confines. The most likely explanation is that these "extra" stars belong to a slowly dissolving dwarf galaxy.

A team led by Kathy Vivas of the Center for Astronomical Investigations in Venezuela had noticed hints of such a beast a few years earlier. The researchers were searching for a type of pulsating variable star known as RR Lyrae stars. "We saw a high density of RR Lyrae stars — over 20 of them — in the region and speculated that they belonged to a small galaxy being cannibalized by the Milky Way," she says. Now, in light of the Sloan findings, "It appears that the stellar stream we detected is itself part of a larger structure."

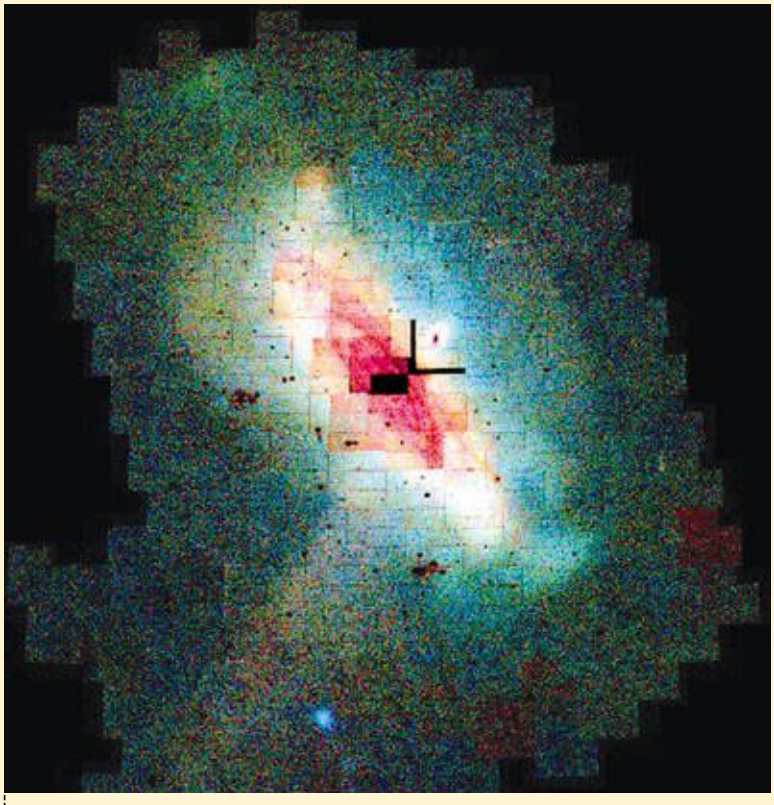
So many tidal trails surround the north galactic pole that researchers dubbed the region the "field of streams."

Field of streams

Later in 2006, Vasily Belokurov and Daniel Zucker of Cambridge University and their collaborators identified a number of other trails and lumps in Sloan images taken toward the north galactic pole, not far from the direction of the previously known Sagittarius and Monoceros streams. So many tidal trails populate this region that the researchers dubbed it the "field of streams."

One newly discovered trail covers 30° of sky. It contains two globular clusters deficient in heavy elements and could be the "orphan" of yet another disrupted dwarf galaxy. At least three more faint Milky Way

THE ANDROMEDA GALAXY (M31) looks serene when viewed from Earth, but it disguises a life of rampant cannibalism. T. A. RECTOR/B. A. WOLPA/NOAO/AURA/NSF



A STELLAR STREAM flows through the Andromeda Galaxy in this computer-processed image from the Isaac Newton Telescope on La Palma. INT/WFC

THE CANNIBAL NEXT DOOR

With evidence of the Milky Way's cannibalism all around us, it seems logical our galaxy's near twin, the massive Andromeda Galaxy (M31), should show signs, too. The nearest large galaxy to our own, the spiral behemoth M31, lies approximately 2.5 million light-years away. That vast distance makes it difficult for astronomers to discern merger relics.

In 1993, a team led by Tod Lauer of the National Optical Astronomy Observatories in Tucson, Arizona, discovered what appear to be two dense knots — or a double nucleus — at M31's center. The researchers needed the Hubble Space Telescope's sharp eyes to separate the two structures. Some astronomers speculated that one of the clumps belonged to a satellite galaxy that had collided with M31.

One problem with this story: The two clumps should have merged in less than 100 million years — a short time compared with the several-billion-year age of the stars in those knots. Most researchers now prefer an alternate explanation, proposed by Scott Tremaine of Princeton University. He thinks both knots belong to a single elongated disk of stars having a supermassive black hole at one focus.

More convincing evidence of M31's cannibalism came to light in 2001. During a deep panoramic imaging survey of the galaxy's halo conducted with the 2.5-meter Isaac Newton Telescope on La Palma in the Canary Islands, Rodrigo Ibata of Strasbourg Observatory and his colleagues discovered a giant stream of stars rich in heavy elements.

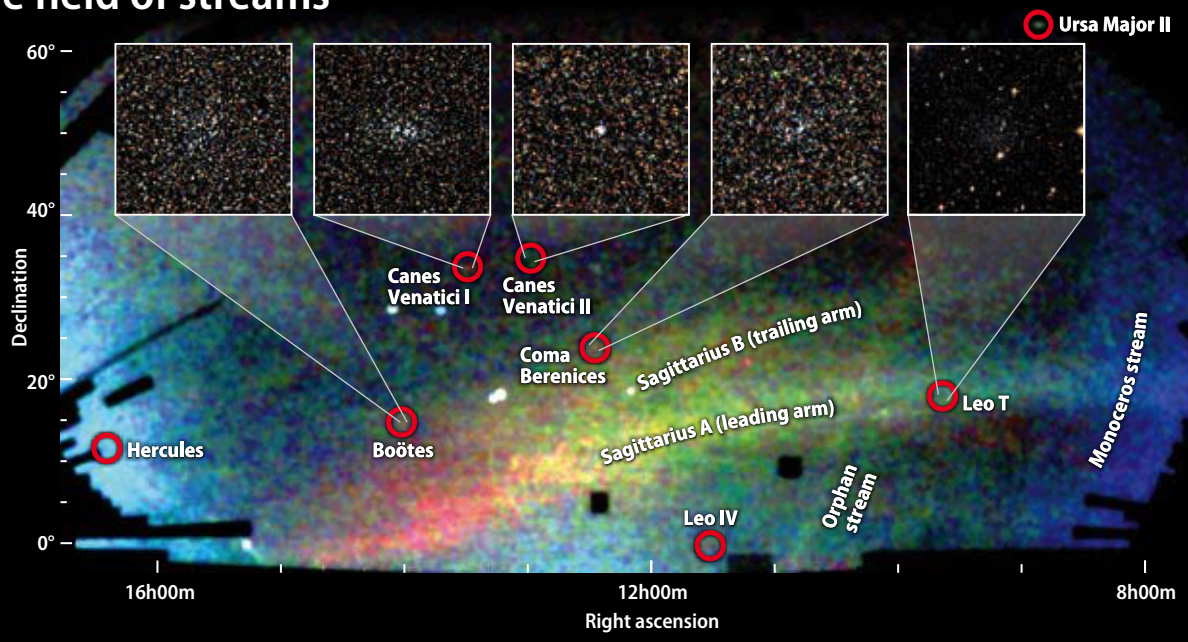
Researchers think the stream originates from tidal forces acting on the peculiar dwarf galaxies M32 and NGC 205, both close companions of M31. The similarity in the abundance of certain elements in the stream with those in the satellite galaxies, the stream's alignment with the dwarfs, and their distorted appearances all support this conclusion.

The following year, a team led by Puragra Guhathakurta of the University of California, Santa Cruz, found another, fainter stream during a deep survey of a narrow strip of M31's halo. "We think we are seeing the debris trail of a small, chemically rich galaxy that fell into Andromeda," explains Guhathakurta. "Even as this galaxy was disrupted by Andromeda, its stars would retain a memory of their original velocity and continue to move as a coherent group."

More recently, the Sloan survey revealed a giant, diffuse clump of stars just outside M31's disk that could be the remnants of another satellite galaxy being torn apart by Andromeda's tides. The exact nature of this structure remains a mystery, however.

Yet another intriguing feature is a faint, extended disk that consists of multiple sub-structures — most likely tidal debris. Ibata's team unraveled this structure in 2005 by taking spectra of some 2,800 stars with the Keck Telescope atop Mauna Kea in Hawaii. Deep, systematic surveys of M31, now underway with several telescopes, will help paint a more complete picture of the chaotic history of the Milky Way's sibling. — *R. J.*

The field of streams



THE NORTHERN SKY is awash with stellar debris cannibalized by the Milky Way from numerous dwarf galaxies. Our galaxy's tidal forces overwhelm the small galaxies' puny self-gravitation. The longest debris stream, which forks into at least two segments, belongs to the Sagittarius dwarf galaxy. In this depiction, blue objects lie closest to Earth and red ones are far away. *ASTRONOMY*: ROEN KELLY, AFTER VASILY BELOKUROV AND THE SDSS-II COLLABORATION

satellites, all showing signs of distortion, turn up in the Sloan survey. Taken together, these findings are "a striking demonstration of multiple merger events going on in the Milky Way right now," says Yanny.

Astronomers now have little doubt our galaxy has enriched itself at others' expense. "In fact, the majority of globular clusters might be relics of accretion events," claims Julio Navarro, a theorist at the University of Massachusetts.

As supporting evidence, he points to the agreement between the distribution of globular clusters around the Milky Way and the density profile of accreted stars in his group's simulations of galaxy formation. He finds a similar match between models and observations of our galaxy's near twin, the Andromeda Galaxy. This suggests galactic cannibalism might be rampant.

> There could have been hundreds of small mergers in the Milky Way's infancy, or just a few major collisions.

The Sun's exotic neighbors

But, the "stolen goods" may not be found just in the galaxy's outer reaches — some interlopers may lurk in the solar neighborhood, too. Timothy Beers of Michigan State University and his collaborators identified a group of stars in the Milky Way's disk that shares the chemical abundance pattern of Omega Centauri, and may have come from the same disrupted parent galaxy.

Another such grouping includes the relatively nearby red-giant star Arcturus. The members of this group move through space in a similar manner to one another, but much slower than most other stars in their vicinity. They also share a distinct chemical imprint.

"You can make a plausible, though not necessarily conclusive, case that these stars came from a disrupted satellite galaxy," says Navarro. His own simulations show tidal debris not only can build up the halo but also contribute to the galaxy's disk. "It may be that most metal-poor stars in the Milky Way's disk originated in various accreted satellites," he argues.

This past December, Sloan researchers announced their discovery of two distinct populations of stars in the galaxy's halo. The two groups orbit the galaxy's center in opposite directions — providing more evidence for multiple mergers in the past.

Unfortunately, it's likely impossible to pin down just how many neighbors the Milky Way has devoured during its long history. There could have been hundreds of small mergers in its infancy, or just a few major collisions that dominated. Detailed observations that characterize large samples of stars could provide the best clues.

Toward that end, astronomers have undertaken a project known as RAVE, for RAdial Velocity Experiment. Since 2003, RAVE has commanded some 230 nights of observing on the 1.2-meter UK Schmidt Telescope at the Anglo-Australian Observatory. The project has taken spectra of nearly 100,000 stars to measure their velocities and compositions. The goal is a million stars by 2010. Meanwhile, an extension to the Sloan survey, called the Sloan Extension for Galactic Understanding and Evolution (SEGUE), is collecting spectra of another 250,000 stars.

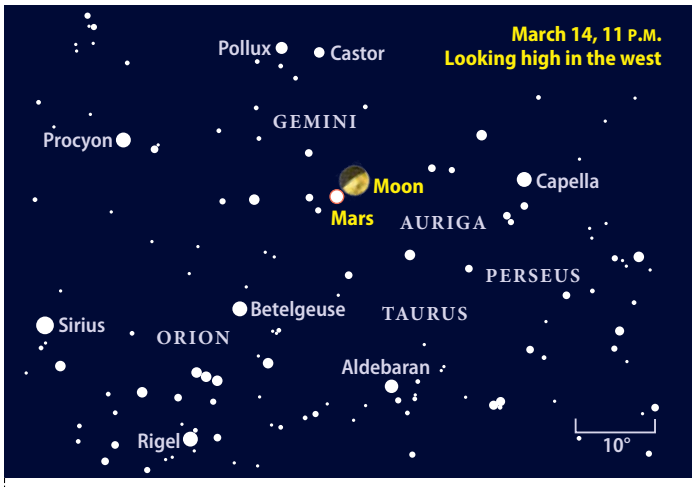
Our galaxy clearly has had a colorful, if not dramatic, history. But the story is far from complete. The challenge for astronomers will be to weave it together from a million pieces scattered in space and time. A

WEB EXTRA To see an animation of M31's ongoing collisions, visit www.Astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

MARCH 08

High on Mars and the Moon



THE MOON PASSES MARS the evening of March 14. Although they appear nearly overhead after sunset, they're a little closer to each other later that evening. *ASTRONOMY:* RICK JOHNSON

Although winter winds still

stir our atmosphere, breaths of warmer air become more frequent as spring approaches. The balmier weather makes for near-perfect viewing. Mars appears high in the sky, on the border of Taurus and Gemini, yet telescopic views have become more of a challenge. Saturn makes up for any martian shortcomings. The ringed planet looks spectacular from its perch in Leo, as it climbs in the east after sunset.

No other planets appear until dawn approaches. Jupiter shines in Sagittarius, while Venus and Mercury come out during early March as the sky brightens before sunrise.

You'll want to start your evening planet viewing with **Mars**. Look for the planet's unmistakable orange glow nearly overhead right after sunset. On March 1, Mars lies due north of Betelgeuse, the red-supergiant star that marks one shoulder of Orion the Hunter. At magnitude 0.2, the planet shines a bit brighter than the star. Mars crosses from Taurus into Gemini March 4. There, it meets up with the First Quarter Moon March 14. By month's end, the planet has dimmed to magnitude 0.8, matching Taurus' brightest star, Aldebaran.

The best telescopic views of Mars for this apparition wrapped up when its apparent diameter fell below 10" in late February. The planet's disk spans 9" in early March and diminishes to 7" by the 31st. This means an 8-inch scope should show some details on Mars' surface when the month begins, but features become difficult to see by late March. Wait for moments of steady air, "good seeing" in the astronomical vernacular, when Earth's

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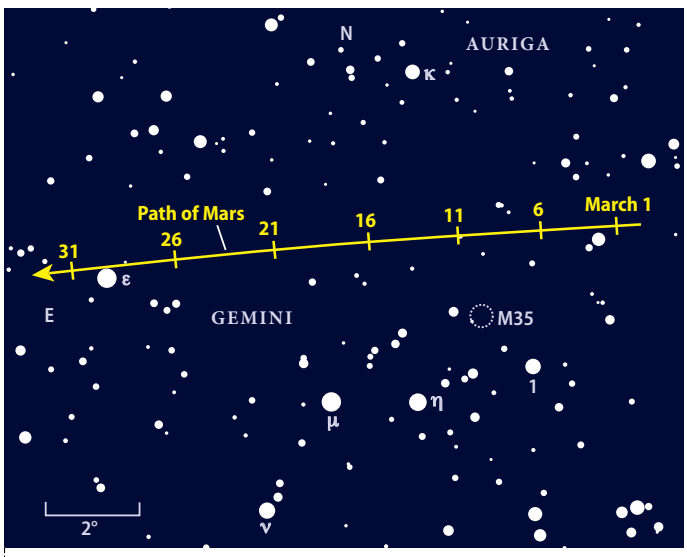
Visible to the naked eye
Visible with binoculars
Visible with a telescope



MARS CRUISES GEMINI for most of March. The planet passes less than 2° north of the constellation's brightest star cluster, M35, on the 9th and 10th. *ASTRONOMY:* RICK JOHNSON

INFRARED UNIVERSE

1.5 million galaxies *revealed*

The Two Micron All Sky Survey gives astronomers the first full 3-D view of the local universe. /// TEXT AND IMAGES BY THOMAS H. JARRETT

The Milky Way's dimly glowing band is rich in gas and dust that block astronomers' views of the universe beyond our galaxy. But between 1997 and 2001, the Two Micron All Sky Survey (2MASS) peered through the dusty screen and gave astronomers a clearer view of the local universe.

Using twin ground-based telescopes located in the Northern and Southern Hemispheres, 2MASS mapped the whole sky at infrared wavelengths between 1 and 2.2 micrometers. These long wavelengths penetrate much of our galaxy's dusty disk. The survey cataloged more than half a billion stars and resolved more than 1.5 million galaxies. In fact, the survey's ability to cut through dust gave astronomers access to never-before-studied galaxies in a region of the sky they traditionally called the "zone of avoidance."

By combining the 2MASS data with redshift measurements — which indicate distance — from other sources, astronomers created the 2MASS Galaxy Redshift Catalog. These data create a 3-D all-sky view of the local universe that extends to about 1.3 billion light-years.

Astronomers could finally see the full "cosmic web" of galaxies beyond the Milky Way. Scattered about space in a vast web-like network, long strings of galaxies terminate where matter has piled up to form massive galaxy clusters. Sheets and bubble-like structures delineate regions of the universe where matter is dense from those where it's sparse.

Understanding the local cosmic web is essential to connecting the origin of structure in the early universe — including dark matter and dark energy, which drive the expanding universe's dynamics — to the subsequent formation of the galaxies we observe today.

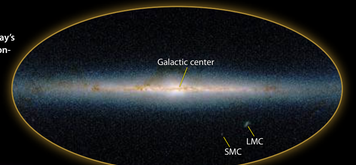
The 2MASS Galaxy Redshift Catalog extends from the Local Group of galaxies within the first few million light-years (including the Milky Way and Andromeda galaxies) to clusters and superclusters of galaxies beyond a billion light-years. The images here show the sky in galactic coordinates so the plane of the Milky Way runs horizontally through the middle. The small, color-coded maps show objects at ever greater distances. We then merged the smaller maps into a single large view to show the full "cosmic web."

The 2MASS Galaxy Redshift Catalog has proven to be a versatile source of data for astronomers. But perhaps its most important function is to provide the "big picture" — the context for analysis and interpretation of data on galaxy clusters, large-scale structure, and the density of matter in the universe. It's a road map that provides a framework for studying the physical connection between the nearby universe and the early cosmos, when the cosmic web formed. ◘

Thomas H. Jarrett *is an astronomer with NASA's Infrared Processing and Analysis Center at the Jet Propulsion Laboratory in Pasadena, California.*

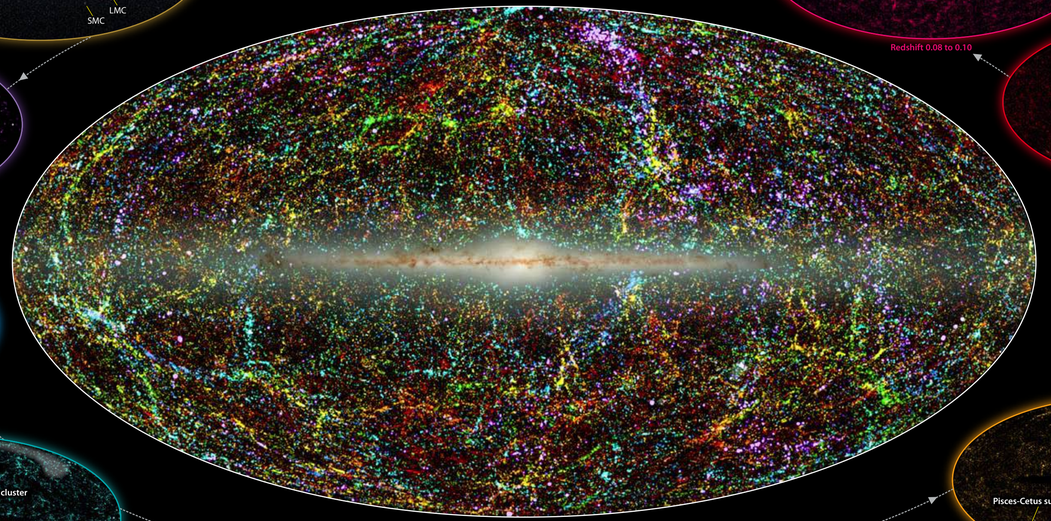
The home galaxy

HALF A BILLION STARS delineate the Milky Way's disk shape. The plane of our galaxy runs horizontally through the middle of this image. The galactic center's starry bulge, located in the constellation Sagittarius, dominates the center. The Milky Way's diminutive satellite galaxies, the Large and Small Magellanic Clouds (LMC and SMC), also appear.



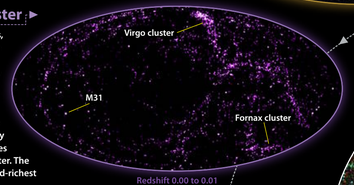
The Cosmic Web

MORE THAN 1.5 MILLION GALAXIES create a cosmic web that embraces half a billion stars in our own Milky Way Galaxy. The all-sky panorama of the local universe below comes courtesy of the 2MASS Point Source and Galaxy Redshift catalogs. Each galaxy is color-coded by its distance: Bluer sources are nearby, redder are more distant. The surrounding maps show slices based on distance, and they identify specific features.



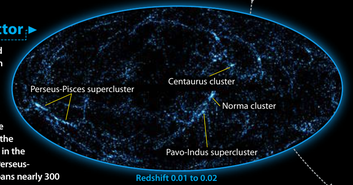
The Local Supercluster

WITHIN 130 MILLION light-years, prominent structures include the galaxies of the Local Group — including the Andromeda Galaxy (M31) — and the Local Supercluster, which contains more than 100 galaxy clusters. Some 2,000 galaxies reside in the Virgo cluster, the most populous nearby galaxy group. The Virgo cluster lies near the Local Supercluster's center. The Fornax cluster ranks as the second-richest galaxy group in this realm.



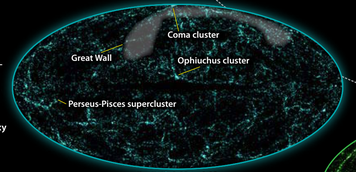
The Great Attractor

BETWEEN 130 MILLION and 261 million light-years lies an aggregate mass so large, astronomers know it simply as the Great Attractor. The immense Local Supercluster itself is moving toward it. The Norma cluster (ACO 3627) is the largest collection of galaxies in the Great Attractor region. The Perseus-Pisces supercluster, which spans nearly 300 million light-years, is one of the universe's largest coherent structures.



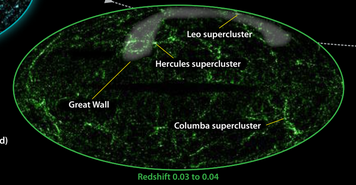
The Great Wall

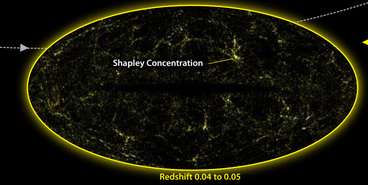
IN 1989, ASTRONOMERS discovered an enormous structure they called the Great Wall (shaded). It lies between 261 and 408 million light-years away, and spans 600 million light-years. In large part, the massive Coma cluster supports this structure. The Perseus-Pisces supercluster remains prominent at this distance. The Ophiuchus galaxy cluster appears just north of the Milky Way's center.



The Hercules supercluster

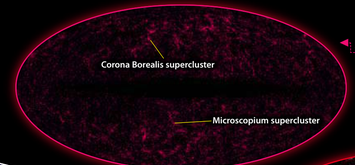
FROM 408 MILLION to 554 million light-years away, the most prominent structures include the Great Wall (shaded) and the Hercules, Leo, and Columba superclusters.





The Shapley Concentration

THE ABELL 3558 galaxy cluster lies near the center of a structure consisting of more than two dozen rich clusters. Called the Shapley Concentration, the supercluster is named for astronomer Harlow Shapley, who discovered it in 1930. This "slice" includes galaxies between 554 million and 685 million light-years away.

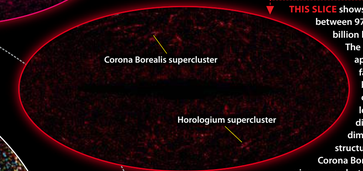


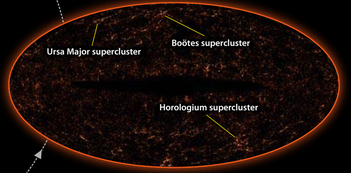
As far as 2MASS can see

THE FINAL SLICE, representing structures from 1.08 billion to 1.37 billion light-years, is as far as astronomers can go with reliably identifying 2MASS galaxies at present. Prominent large-scale structures here include the Corona Borealis and Microscopium superclusters.

A billion light-years

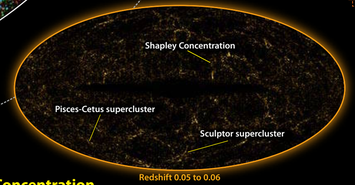
THIS SLICE shows cosmic structures between 978 million and 1.08 billion light-years away. The universe's web-like appearance starts to fade as distances based on galaxy color and brightness lose their ability to discern the third dimension. Stand-out structures include the Corona Borealis and Horologium superclusters.





Boötes supercluster

BETWEEN 815 MILLION and 978 million light-years, prominent large-scale structures include the Ursa Major, Boötes, and Horologium superclusters.



The Sculptor supercluster

THE FAR SIDE of the Shapley Concentration appears in this slice, which shows galaxies between 685 million and 815 million light-years away. The Pisces-Cetus supercluster, located behind the Perseus-Pisces supercluster, now comes into view. The Sculptor supercluster dominates the southern sky.

The Two Micron All Sky Survey is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by NASA and the National Science Foundation.

Astronomy magazine

SUPER SURVEY

Encyclopedia *galactica*

From asteroids to quasars, the Sloan Digital Sky Survey mapped a quarter of the sky in the greatest detail ever. /// BY FRANCIS REDDY

When the Sloan Digital Sky Survey (SDSS) makes its final data release later this year, the volume of astronomical information the project delivers will be comparable to all of the holdings in the U.S. Library of Congress. SDSS is nothing less than an encyclopedia on one-quarter of the night sky.

"There is far more science in the survey than our scientists could ever keep up with," explains the University of Chicago's Richard Kron, the project's director. SDSS observations during the last 7 years created online catalogs containing more than 10,000 gigabytes — some 2,100 DVDs — of images and spectra. This includes some 287 million objects and 1.27 million stellar, galaxy, and quasar spectra. SDSS, says Kron, sets the bar for new wide-field surveys now being planned.

The project began in the mid-1980s, when redshift surveys with distances for thousands of galaxies were showing the first hints of a so-called cosmic web of large-scale structure. This galactic superstructure soon became evident, with galaxies occurring in immense filaments and sheets that were separated by enormous bubble-like voids of nearly empty space.

SDSS' early organizers wanted to best such surveys by measuring the positions and distances of 1 million galaxies in a continuous patch of sky. Rather than select the galaxies from existing photographic surveys, the team wanted to use a large charge-coupled device (CCD) camera to image the entire region in multiple wavelengths. It would be the most ambitious sky-mapping project ever undertaken.

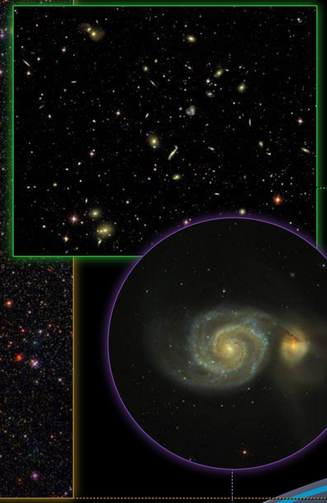
More than a decade passed before the project's 2.5-meter telescope at Apache Point Observatory in New Mexico returned its first high-resolution image. The project saw "first light" in May 1998, began routine operations in April 2000, and made the first of its annual public data releases in 2001. Skygazers can explore the most recent data via the SDSS SkyServer (cas.sdss.org) and through the Sky feature of Google Earth (earth.google.com/sky).

A 3-year extension to the survey, called SDSS-II, wraps up this summer. SDSS-II involves more than 300 astronomers, astrophysicists, and engineers around the world, yet more than half of the scientific papers published using survey data come from researchers outside the project's consortium. "This is a clear indication that we've kept our promise to the scientific community" of timely, high-quality data, says Johns Hopkins University's Alex Szalay, who helped create software that "mines" the survey's wealth of information.

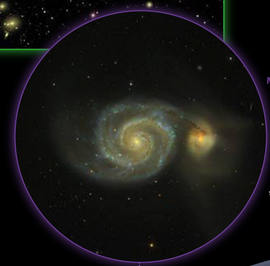
SDSS-II includes the Sloan Extension for Galactic Understanding and Exploration (SEGUE), which maps the structure and stellar makeup of the Milky Way, and the Sloan Supernova Survey, which locates exploding stars to help astronomers better understand the universe's expansion. Recent results from SDSS-II include the discovery of eight dwarf galaxies orbiting our Milky Way and 197 confirmed type Ia supernovae in other galaxies. Where SDSS leaves off, the next decade's planned surveys will begin. ■

Francis Reddy *is a senior editor of* Astronomy.

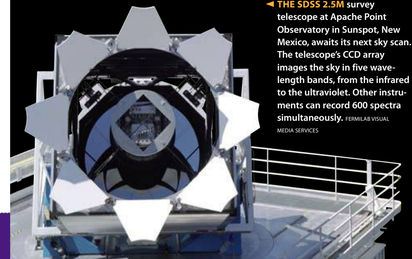
COLOR IMAGES made from SDSS data take some getting used to. In this view of the Cave Nebula (Sh 2–155) in Cepheus, green replaces the vivid reds and magentas we normally associate with a glowing cloud of hydrogen gas. Astronomers combine SDSS green, red, and infrared exposures to make "pretty pictures" such as this. DOUGLAS FINKBEINER (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS)



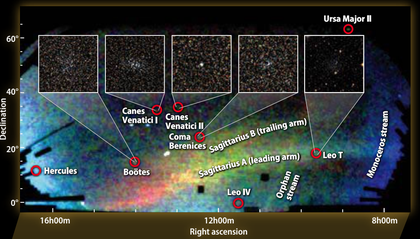
THE HERCULES GALAXY CLUSTER, located some 500 million light-years away, is well known for its large spiral population. Elliptical galaxies, which lack the gas and dust to make new stars, are sparse here. Many of the cluster's galaxies appear to interact. Collisions and mergers may strip gas and dust from spirals that take part, thus creating ellipticals. For this reason, most astronomers think the Hercules galaxy cluster is relatively young. ROBERT LUPTON AND THE SLOAN DIGITAL SKY SURVEY CONSORTIUM



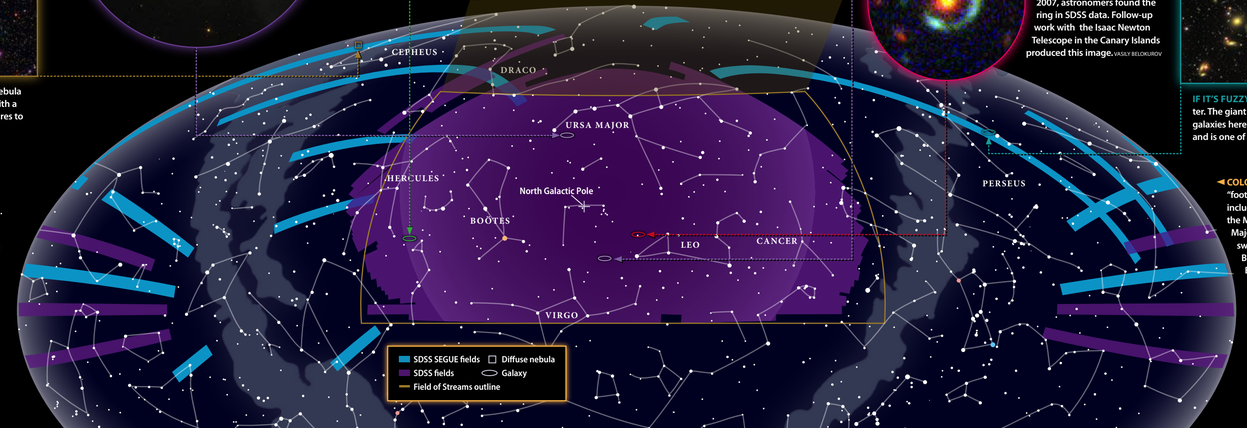
M51, THE WHIRLPOOL GALAXY in the constellation Canes Venatici, lies about 30 million light-years away. This SDSS view brings out details in the faint tidal tails produced as M51's companion, galaxy NGC 5195 (right), passes near. ROBERT LUPTON AND THE SLOAN DIGITAL SKY SURVEY CONSORTIUM



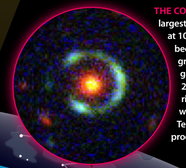
◄ **THE SDSS 2.5M** survey telescope at Apache Point Observatory in Sunspot, New Mexico, awaits its next sky scan. The telescope's CCD array images the sky in five wavelength bands, from the infrared to the ultraviolet. Other instruments can record 600 spectra simultaneously. FERMILAB VISUAL MEDIA SERVICES



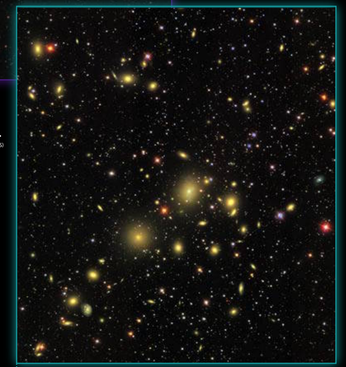
THE MILKY WAY'S eight newest satellite galaxies were found when an international team of astronomers used SDSS-II data to map streams of stars coursing through our galaxy's halo. "We've found almost as many new Milky Way satellites as were detected in the previous 70 years," says team member Vasily Belokurov of England's Cambridge University. The region contains at least four streams of halo stars, which is why the astronomers dubbed this area the "field of streams" (outlined below). Two new dwarfs lie in the constellation Canes Venatici, one in Boötes, one in Leo, one in Coma Berenices, one in Ursa Major, and one in Hercules. "They look as though they're being ground up," Belokurov says. Tides from the Milky Way are the most likely reason. *ASTRONOMY:* ROEN KELLY, AFTER VASILY BELOKUROV AND THE SDSS-II COLLABORATION



ONE OF THE BRIGHTEST members of the Virgo cluster of galaxies, M86, is also the brightest galaxy in this SDSS mosaic. The cluster lies about 48 million light-years away. DOUGLAS FINKBEINER (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS)



THE COSMIC HORSESHOE is the largest optical Einstein ring known, at 10.2" across. The ring forms because a foreground galaxy's gravity warps a background galaxy's light into an arc. In 2007, astronomers found the ring in SDSS data. Follow-up work with the Isaac Newton Telescope in the Canary Islands produced this image. VASILY BELOKUROV



IF IT'S FUZZY, it's a galaxy in this SDSS mosaic of the Perseus galaxy cluster. The giant elliptical galaxy NGC 1275 (center) rules over thousands of galaxies here. The galaxy cluster lies some 300 million light-years away and is one of the closest. ROBERT LUPTON AND THE SLOAN DIGITAL SKY SURVEY CONSORTIUM

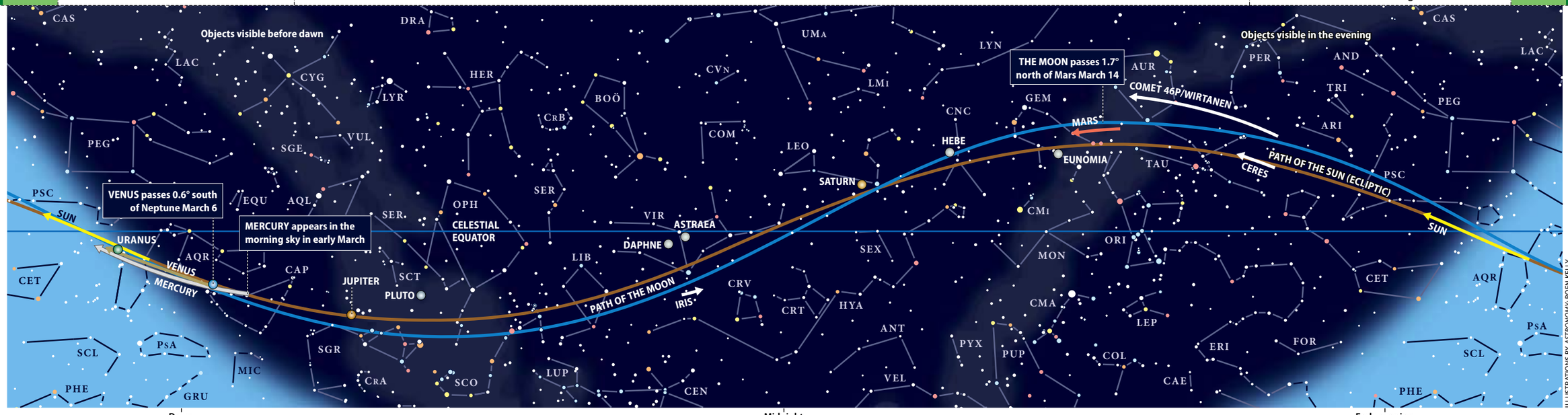
◄ **COLORED STRIPES** show the Sloan Digital Sky Survey's (SDSS) "footprint" on the sky. The contiguous survey region, which includes the North Galactic Pole, provides a view directly out of the Milky Way's plane. It includes Hercules, Leo, Virgo, and Ursa Major (the constellation containing the Big Dipper). Purple swaths show regions imaged during the survey's first 5 years. Blue stripes contain areas imaged as part of SDSS-II's Sloan Extension for Galactic Understanding and Exploration (SEGUE), which samples areas both in and out of our galaxy's plane. MARK SUBBARAO (SPACE VISUALIZATION LABORATORY, ADLER PLANETARIUM AND ASTRONOMY MUSEUM)/ASTRONOMY: ROEN KELLY

Astronomy magazine

Planets in March

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine



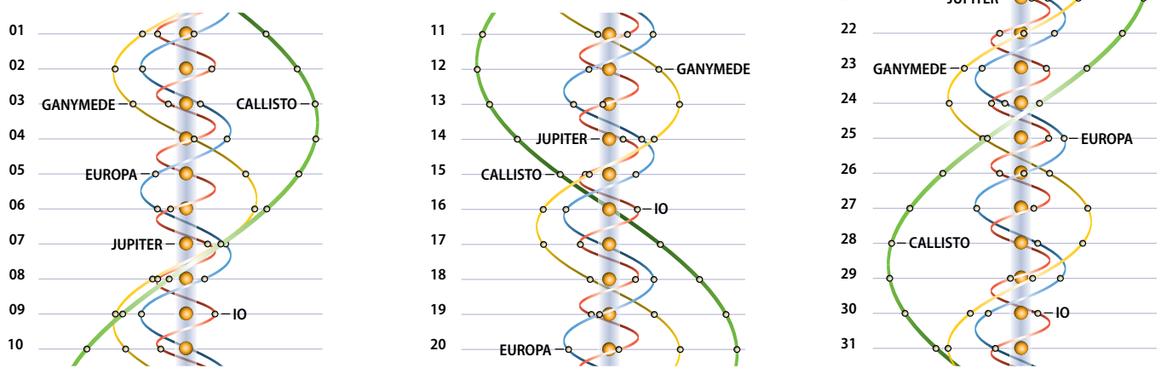
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	March 1	March 15	March 15	March 15	March 15	March 15	March 15	March 15	March 15
Magnitude	0.1	–0.1	–3.8	0.5	–2.0	0.3	5.9	8.0	14.0
Angular size	7.4"	6.1"	10.8"	8.0"	35.6"	19.9"	3.3"	2.2"	0.1"
Illumination	53%	72%	93%	90%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.911	1.110	1.543	1.170	5.530	8.352	21.086	30.881	31.524
Distance (AU) from Sun	0.451	0.465	0.728	1.649	5.221	9.286	20.096	30.041	31.431
Right ascension (2000.0)	21h04.4m	22h10.8m	22h19.2m	6h15.9m	19h17.0m	10h24.5m	23h20.3m	21h41.0m	18h03.9m
Declination (2000.0)	–16°40'	–13°11'	–11°40'	25°58'	–22°12'	11°57'	–5°04'	–14°12'	–17°06'

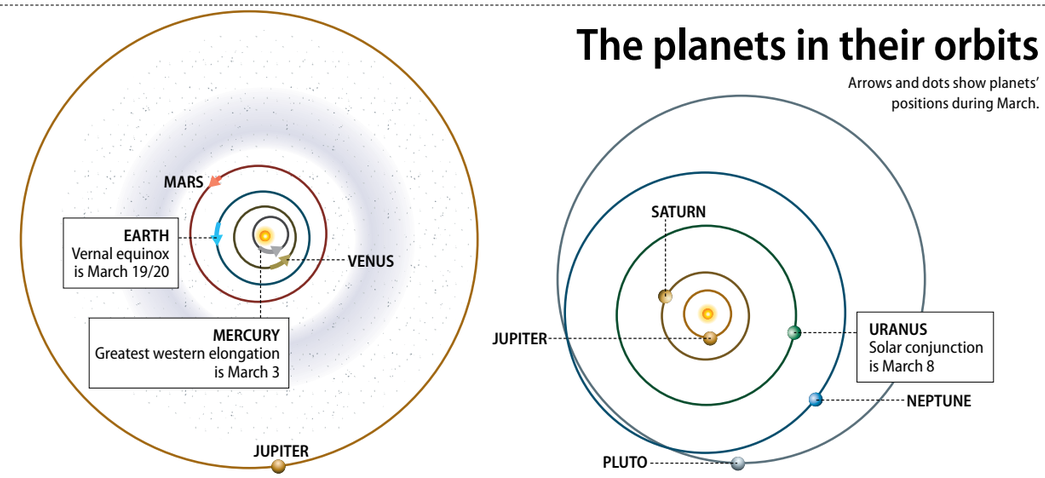
Jupiter's moons

Dots display positions of Galilean satellites at 6 A.M. EDT on date shown. South is at top to match the view through a telescope.



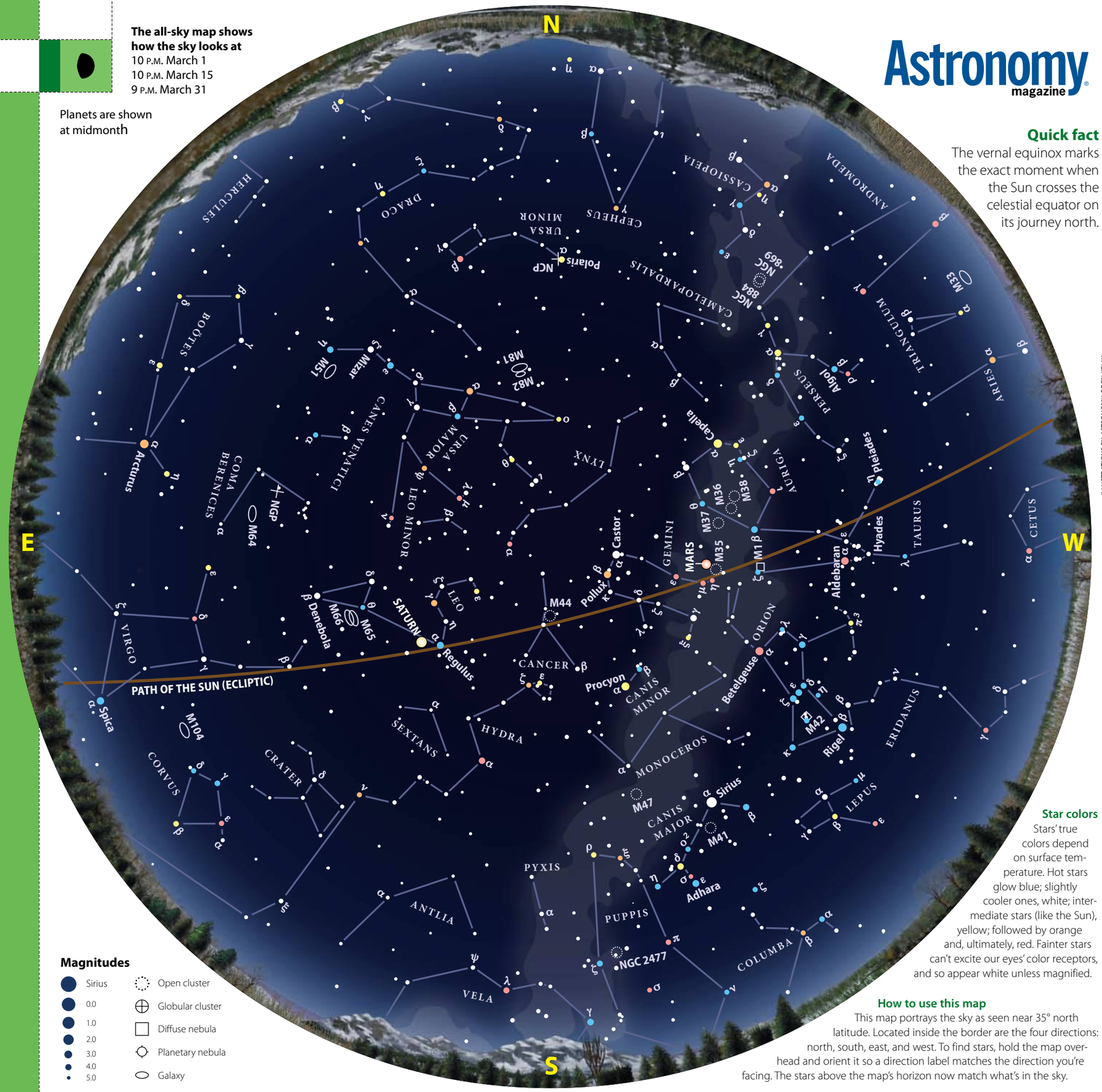
The planets in their orbits

Arrows and dots show planets' positions during March.



The all-sky map shows how the sky looks at
10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth



Magnitudes

Sirius	Open cluster
0.0	Globular cluster
1.0	Diffuse nebula
2.0	Planetary nebula
3.0	Galaxy
4.0	
5.0	

Star colors
Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Astronomy magazine

Quick fact
The vernal equinox marks the exact moment when the Sun crosses the celestial equator on its journey north.

NOTABLE OBSERVING DATE:
March 14, when the First Quarter Moon passes 1.7° north of Mars.

march 08

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						[01]
[02]	[03]	[04]	[05]	[06]	[07]	[08]
[09]	[10]	[11]	[12]	[13]	[14]	[15]
[16]	[17]	[18]	[19]	[20]	[21]	[22]
[23]	[24]	[25]	[26]	[27]	[28]	[29]
[30]	[31]					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

02 The Moon passes 4° south of Jupiter, 8 P.M. EST

03 Mercury is at greatest western elongation (27°), 6 A.M. EST

05 The Moon passes 0.2° south of Mercury, 9 A.M. EST

The Moon passes 0.2° north of Venus, 2 P.M. EST

06 Venus passes 0.6° south of Neptune, 3 P.M. EST

07 New Moon occurs at 12:14 P.M. EST

08 Uranus is in conjunction with the Sun, 3 P.M. EST

10 The Moon is at perigee (227,607 miles from Earth), 5:39 P.M. EDT

14 First Quarter Moon occurs at 6:46 A.M. EDT

The Moon passes 1.7° north of Mars, 11 P.M. EDT

19 The Moon passes 0.8° south of Regulus, 4 A.M. EDT

The Moon passes 3° south of Saturn, 11 A.M. EDT

20 Vernal equinox occurs at 1:48 A.M. EDT

21 Full Moon occurs at 2:40 P.M. EDT

23 Mercury passes 1.0° south of Venus, 6 A.M. EDT

26 The Moon is at apogee (251,713 miles from Earth), 4:13 P.M. EDT

27 The Moon passes 0.5° south of Antares, 6 A.M. EDT

29 Last Quarter Moon occurs at 5:47 P.M. EDT

Asteroid Pallas is in conjunction with the Sun, 8 P.M. EDT

30 The Moon passes 3° south of Jupiter, 1 P.M. EDT

WEB EXTRA For definitions of terms, visit www.Astronomy.com/glossary.

— *Continued from page 40*

turbulent atmosphere settles down and the image sharpens.

Watch for an attractive binocular pairing when Mars passes north of Gemini's bright open star cluster, M35. Mars lies 1.7° north of M35 March 9 and 10. The cluster sports several yellow and orange giant stars; Mars' orange glow will complement their appearance. The planet's eastward motion relative to the background stars carries it into central Gemini by the end of March, when it lies near Epsilon (ε) Geminorum.

Saturn remains visible nearly all night among the stars of Leo. The ringed planet reached opposition and peak visibility February 24, so it stays a prominent object throughout March. It shines a full magnitude brighter than Regulus, Leo's brightest star, which lies a few degrees west of Saturn. By March 31, Saturn and Regulus stand high in the southeast once the sky darkens.

Saturn looks beautiful through any telescope. Take your time — quick glances miss the details. Saturn's disk currently spans 20", so it appears small in the eyepiece. Yet, you can usually spy the dark band of the South Equatorial Belt. Finer details show up only to patient viewers who wait for brief moments of good seeing.

What sets Saturn apart is its magnificent ring system. This month, the rings span 45" east-to-west and 7" north-to-south. The Cassini Division appears clearly as a dark gap near the eastern and western ends of the rings. As Saturn moves away from opposition, the planet's shadow grows conspicuous on the rings' far side, just east of the disk. Catch the rings now — by late this year, they will nearly disappear as Saturn and Earth line up for a ring-plane crossing in 2009.

Saturn has a family of at least 60 moons, a handful of which glow bright enough to see through backyard scopes. The brightest moon, Titan, takes 16 days to orbit Saturn. At magnitude 8.4, it's usually the brightest "star" visible close to Saturn (although background stars occasionally lie in the field as well). Titan passes due north of Saturn March 9 and 25, and due south of the planet March 1 and 17.

Iapetus, perhaps Saturn's oddest moon, lies far west of Saturn as February turns to

Martin Ratcliffe *is the author of* State of the Universe 2008 *(Praxis, 2007).* **Alister Ling** *is a meteorologist for Environment Canada.*

A FIRST QUARTER BONANZA

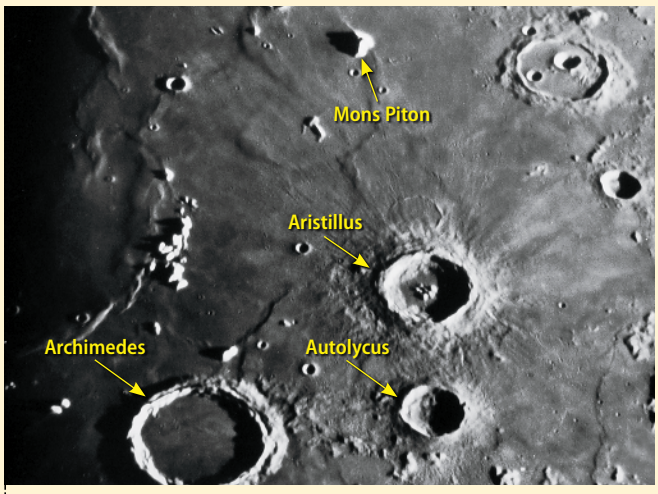
After admiring the naked-eye view of the First Quarter Moon near Mars the evening of March 14, aim your telescope at the striking sights north of the lunar equator. The best views will come along the terminator — the dividing line between darkness and light on our satellite's surface. Look for the rugged lunar Apennines thrusting diagonally into the Moon's sunlit domain.

Just north of this mountain range lie two relatively young craters — Autolycus and Aristillus — that stand out in the plains of Mare Imbrium. Their high walls catch the sunlight and keep the central peaks and floors in shadow March 14. From North America that evening, the large crater Archimedes lies on the terminator with its eastern wall fully lit.

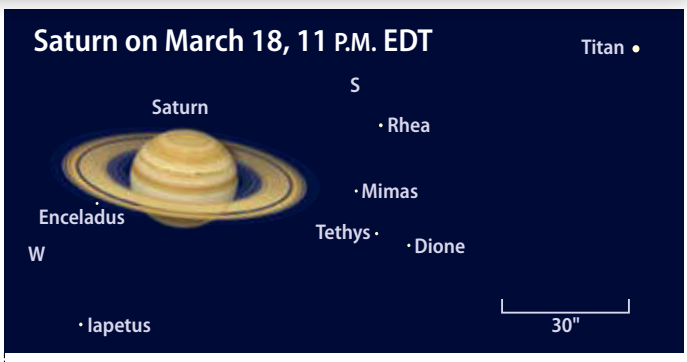
As the evening progresses, its western rim slowly lights up until a ring appears, half of it surrounded by darkness. A few nights later, Archimedes' flat, lava-filled floor will look noticeably different from the younger craters to its east.

Just north of these craters lies the conspicuous Mons Piton, a solitary peak that juts above the plain. If you catch it early enough, Piton casts a long shadow that extends into the blackness of the Moon's unlit half. On the evening of March 14, come back every hour or so to see how quickly the shadow shortens with lunar sunrise.

Piton, a relic of the huge Mare Imbrium impact, towers 1.4 miles above the surrounding plain. Piton appears isolated because lava buried its companion peaks. The low Sun angle on the 14th should highlight the tiny crater sitting atop Piton's summit. You'll need a night with good seeing to identify this crater.



THE LUNAR TERMINATOR highlights stark mountains and giant craters when the Moon reaches first quarter phase March 14.



SATURN'S MOONS always put on a good show, but it's rare to have distant Iapetus join its siblings. *ASTRONOMY:* RICK JOHNSON

METEORS WITHOUT A HOME

The winter doldrums continue in March, with no major meteor shower on display. Instead, you'll have to look for sporadic meteors — random flotsam sailing into Earth's atmosphere from no common source. On average, sporadics occur once every 10 to 15 minutes from any place on Earth.

Early morning hours are always best for meteor watching. At that time, you're on Earth's leading hemisphere as our planet orbits the Sun. Any meteors that appear in the predawn hours collide head-on with Earth, and the higher impact velocity with our atmosphere produces brighter meteors.

/// WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mars (south)	Mars (west)	Mercury (east)
Saturn (east)	Saturn (south)	Venus (east)
		Jupiter (southeast)
		Saturn (west)

March. This orients the two-faced moon with its brighter hemisphere toward Earth, so it glows brightest, at magnitude 10.1. You'll easily see Iapetus about 10' (30 Saturn diameters) due west of Saturn. When this moon lies east of Saturn, as it will in late March, it appears 5 times fainter and is much harder to see.

When astronomer Giovanni Cassini observed Iapetus in the late 17th century, he reported he could see the moon only when it was west of Saturn. He deduced that light material covered one of the moon's hemispheres while dark material coated the opposite one. The Voyager spacecraft confirmed this idea in the early 1980s. The Cassini spacecraft recently returned detailed images of the boundary between the dark and bright regions. (See "Exploring Iapetus' dark side" on page 60.)

Follow Iapetus early this month as it fades and moves closer to Saturn. It passes due north of Saturn March 18/19, when it glows half as bright as it did on the 1st. Its faintness and

JUPITER'S CLOUD TOPS sported a new look in 2007, as the normally dark South Equatorial Belt (just below the Great Red Spot) nearly disappeared. The inner moon Io lies just off Jupiter's limb in this image. MIKE SALWAY

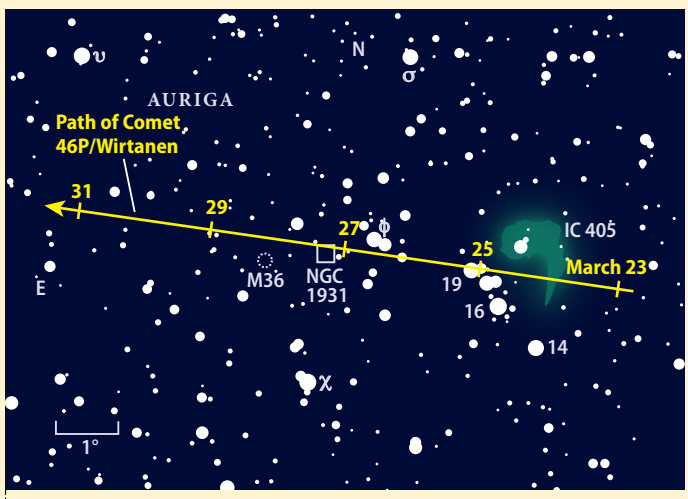
REAL COMET OCCULTS A FAKE ONE

Within easy reach of a 4-inch telescope under a dark sky, Comet 46P/Wirtanen glides toward the Milky Way in Auriga. The first Moon-free observing window closes around March 10, when the waxing crescent Moon spreads its veil of light. The next dark window opens March 23 for a couple of hours, then widens as the gibbous Moon rises later each succeeding night.

A nice wide-field photo opportunity happens March 24 and 25, when the 9th-magnitude comet spreads a short tail between two large gas clouds, the famous one being the Flaming Star Nebula (IC 405). Although prominent in pictures, these nebulae are difficult to see visually and require a transparent sky.

The treat of the month takes place March 27, when Wirtanen shares the same high-power field as NGC 1931. A handful of stars buried in an out-of-round cocoon of emission and reflection nebulosity makes NGC 1931 masquerade as a comet. With a real comet in the same field, however, you can see the resemblance is superficial. The most obvious difference is a bow-shaped feature on the comet's western flank caused by the Sun's interaction with the comet's gas and dust. As the sky grows dark, you may not be able to tell where the comet's tail ends and the background nebula begins.

Follow the pair closely over the next 4 hours as they seem to merge and then separate.



COMET 46P/WIRTANEN should glow around 9th magnitude in the evening sky as it passes several impressive deep-sky objects in Auriga. *ASTRONOMY*: RICK JOHNSON

This encounter should deliver a spectacular time-lapse sequence for digital photographers.

One night later (the 28th), Comet Wirtanen's core lies less than half a degree from the bright, splashy star cluster M36. The two objects could not look or be more different, so enjoy the contrast.

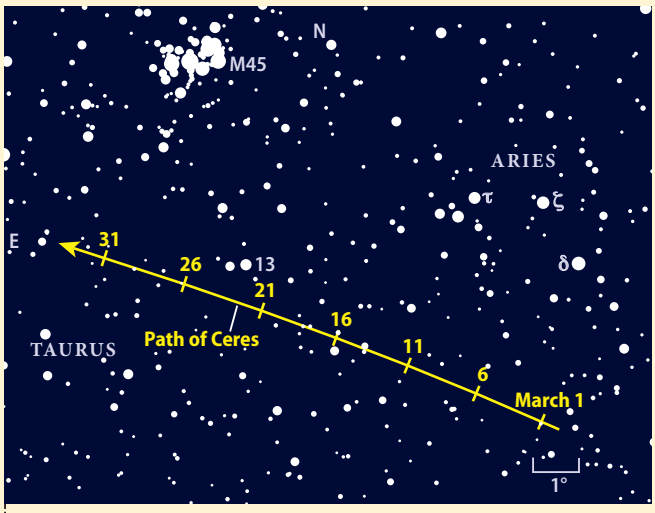
CERES MEETS THE SEVEN SISTERS

Asteroid 1 Ceres travels eastward this month, slowly picking up speed as its orbit carries it farther away from Earth. At the end of March's first week, the 595-mile-wide space rock abandons the fertile pasture of Aries the Ram for that of Taurus the Bull.

Glowing at 9th magnitude, Ceres shows up through binoculars and stands out in a telescope's field of view. It reflects only 12 percent of the sunlight that falls on its mottled, crater-pocked surface. This matches the Moon's average value. (When Earth swings around early next year, Ceres will appear noticeably brighter because the asteroid will be much closer to Earth.)

On the evenings of March 14 and 15, the dwarf planet passes through a squashed box of four slightly brighter stars that spans about half a degree, the apparent size of the Moon. These reference markers make it easy to track Ceres' movement from night to night. If you have good eyes and steady seeing conditions, you might even notice the relative motion during a single evening.

Between March 22 and 27, Ceres slides 5° south of the Pleiades star cluster (M45), also known as the Seven Sisters. This cluster is the brightest object in Charles Messier's famed list of deep-sky objects.



ASTEROID CERES this month crosses from Aries into Taurus, where it passes 5° south of the Pleiades star cluster. *ASTRONOMY*: RICK JOHNSON

proximity to Saturn's bright disk (less than 30" away) make it significantly harder to see.

You'll have to wait awhile before the next planet comes into view. As Saturn descends toward the western horizon, **Jupiter** climbs in the southeast. On March 1, it rises around 4 A.M. local time. It comes up some 90 minutes earlier by month's end. Jupiter shines at magnitude –2.0, easily besting the background stars of Sagittarius. On March 2, you'll find the 3rd-magnitude star Pi (π) Sagittarii 1° north of the planet and a waning crescent Moon about 10° to their right. The Moon returns to this vicinity again March 30, when it stands 5° to Jupiter's lower right.

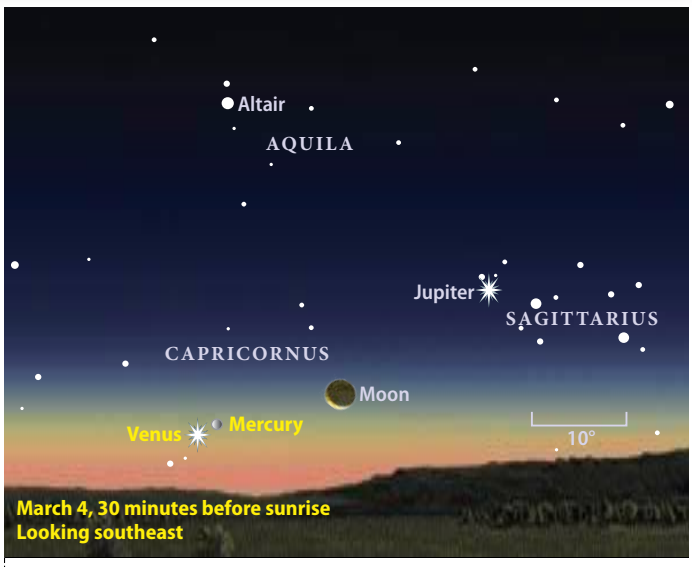
Although Jupiter remains fairly low as dawn approaches, its 36"-diameter disk should prove a wonderful sight through most telescopes. The planet's cloud belts have shown dramatic changes during the past 12 to 18 months, and it will be fascinating to see how long this turmoil lasts.

Last year, Jupiter's dark North Equatorial Belt appeared more prominent than the South Equatorial Belt, and both the latter belt and its neighbor, the South Tropical Zone, underwent major changes. Now that Jupiter has reappeared after solar conjunction, backyard observers will be keen to follow what's happening in 2008.

In early March, **Venus** and **Mercury** appear together low in the predawn sky. On March 1, they lie 2° apart. (They were slightly closer in late February.) Venus shines at magnitude –3.9, four magnitudes brighter than Mercury.

The two inner planets rise an hour before the Sun, so find a spot with a flat horizon toward the east-southeast if you plan to view them. Half an hour before sunrise March 1, Venus stands 5° high in the brightening twilight, with Mercury to its upper right. You'll likely need binoculars to spot Mercury.

The pair remains close throughout March. On the 23rd, Mercury passes 1° south of Venus. The two planets lie within a few degrees of the horizon, however, and will be hard to spot even with binoculars.



MERCURY AND VENUS skim the southeastern horizon before dawn in early March, but you may need binoculars to see them both low in the twilit sky. *ASTRONOMY*: RICK JOHNSON

Neptune lies in eastern Capricornus but appears too low before dawn to spot easily. You might try to find it March 6, when brilliant Venus serves as a guide less than 1° south of Neptune.

Once again, spring gradually returns to mid-northern latitudes, in a wave of growth that pushes northward during March and April.

The vernal equinox occurs at 1:48 A.M. EDT March 20, marking the precise moment when the Sun crosses the celestial equator heading from south to north.

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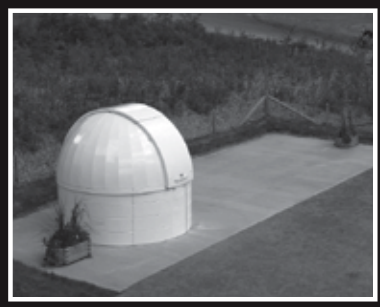

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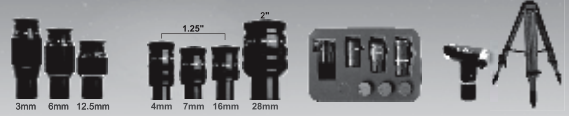

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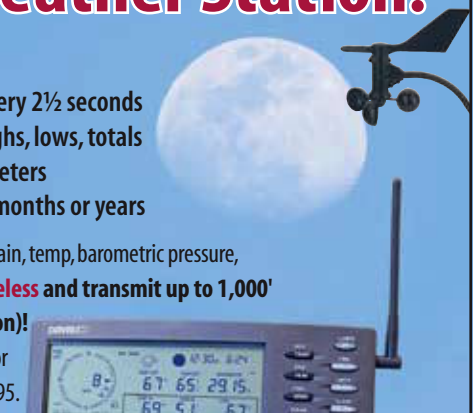

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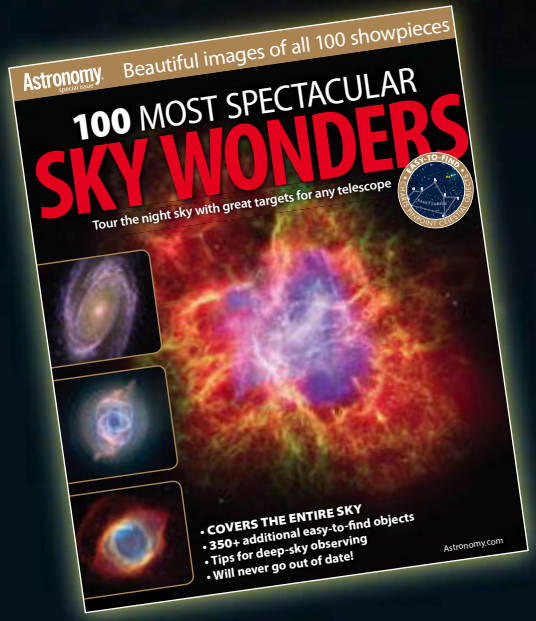
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These examples represent the traditional relationship of science and religion that is too often obscured by the divisive, hot-headed rhetoric and the gross oversimplifications we often see in today's headlines. Long before the shouting and the sloganeering, scientists and theologians have pursued a unity of truth, and most theologians have agreed with the advice of Galileo's colleague, Cardinal Baronio, that the Bible "tells us how to go to heaven, not how the heavens go."

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Dr. Lawrence M. Principe is Professor of the History of Science and Technology, and Professor of Chemistry at Johns Hopkins University. He received a Ph.D. in Organic Chemistry from Indiana University and a Ph.D. in the History of Science from Johns Hopkins University. He has won several Johns Hopkins teaching awards and the 2004 Francis Bacon Prize from the California Institute of Technology.

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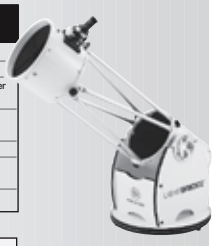

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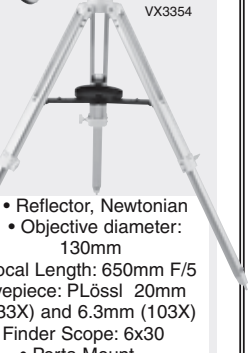

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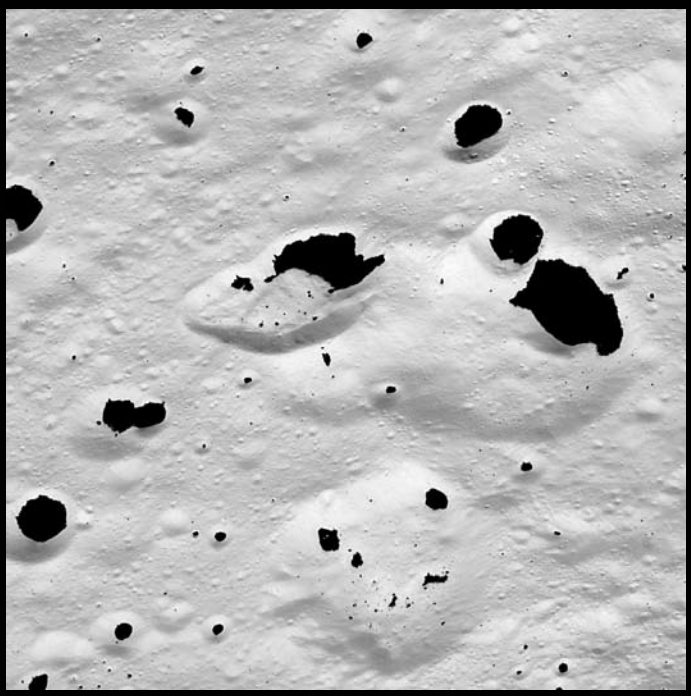
Exploring Iapetus' dark side

The Cassini spacecraft's recent flyby of Saturn's strangest moon may have solved one mystery, but it leaves many more. /// BY RICHARD TALCOTT

Astronomers occasionally use words like "weird," "strange," or "bizarre" to describe their latest findings. And sometimes discoveries still seem strange centuries after they're made. That's where scientists find themselves when discussing Saturn's moon Iapetus.

Iapetus (pronounced eye-APP-eh-tuss) has a split personality: Half of it is as bright as newly fallen snow and half as dark as freshly laid tar. But the moon finally may be shedding its cloak of mystery. On September 10, the Cassini spacecraft skimmed just 1,022 miles (1,644 kilometers) above the moon's surface, nearly 100 times closer than any other Iapetus encounter.

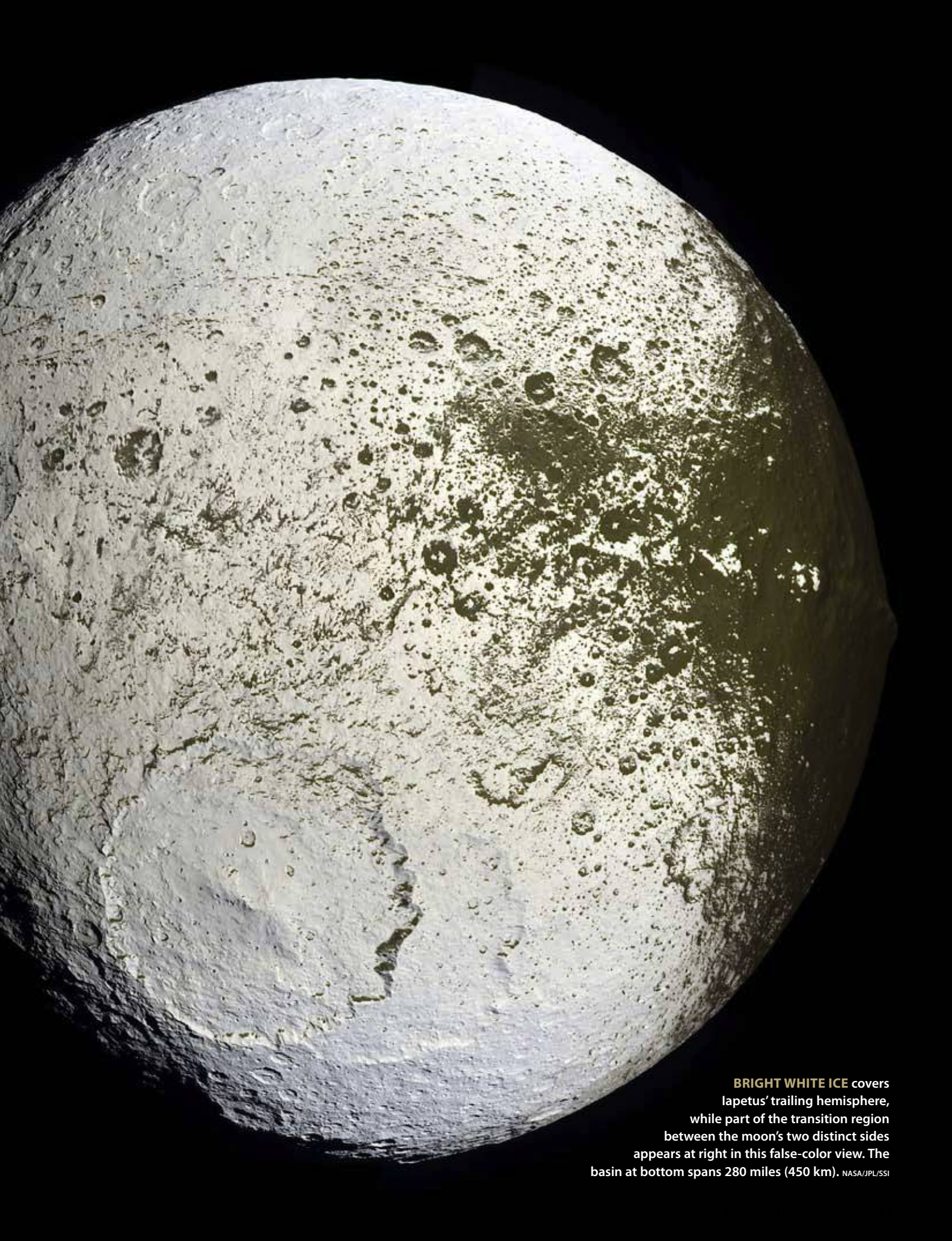
Images and other observations show the moon likely suffers from a runaway process that transports vaporized water ice from the dark hemisphere to the bright one. The process, called "thermal segregation," quickly divides Iapetus into a world of black and white with virtually no shades of gray. Despite the new observations, scientists have yet to figure out where the dark material comes from.



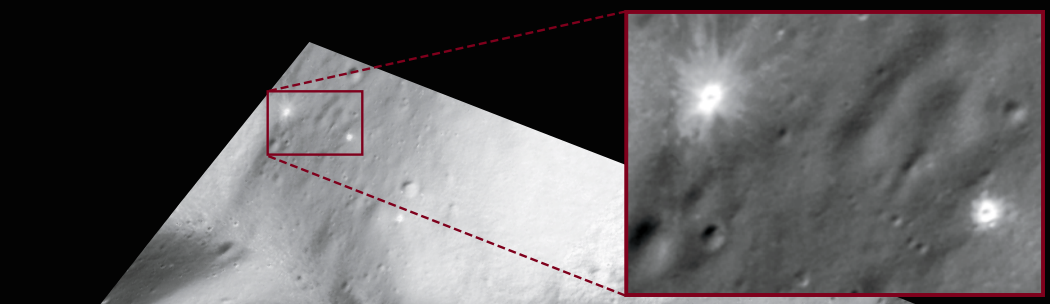
The lone flyby

The stakes were high as Cassini approached Iapetus in early September. Because the moon orbits so far from Saturn — 2.21 million miles (3.56 million km) — mission planners designed only one close flyby. It went off without a hitch. "Our flight over the surface of Iapetus was like a non-stop freefall, down the rabbit hole, directly into Wonderland," exclaimed Cassini imaging team leader Carolyn Porco of the Space Science Institute in Boulder, Colorado.

◀ **BLACK AND WHITE** coexist in Iapetus' transition region. Dark material, likely made of carbon compounds, thinly covers bright water ice at the bottoms of craters. NASA/JPL/SSI

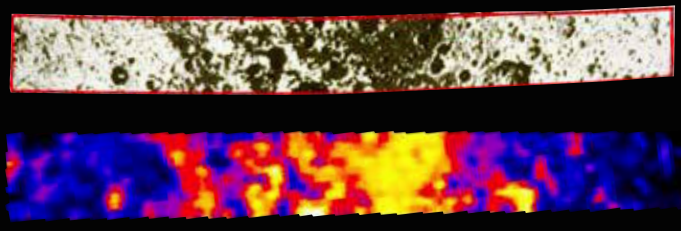


BRIGHT WHITE ICE covers Iapetus' trailing hemisphere, while part of the transition region between the moon's two distinct sides appears at right in this false-color view. The basin at bottom spans 280 miles (450 km). NASA/JPL/SSI



◀ **BRIGHT RAYS** of excavated ice emanate from the leftmost impact crater in this close-up. The imaging team darkened the crater so it would not look overexposed. NASA/JPL/SSI

▲ **THE SHARPEST VIEW** ever of Iapetus came as Cassini swooped low over dark terrain near the moon's equator. Here, tiny, shallow craters punch through the dark veneer to reveal white ice underneath. This eight-image mosaic reveals details as small as 33 feet (10m) across. NASA/JPL/SSI



◀ **TEMPERATURE EXTREMES** on Iapetus reflect the differences between white and dark material. This heat scan (bottom) cuts across bright, dark, and transitional regions (seen in visible light, above). The temperature peaks in dark terrain at –229° F (shown as white and yellow) and reaches a minimum in bright areas at –256° F (dark blue). NASA/JPL/GSFC/SwRI/SSI

Cassini snapped approximately 450 images during the relatively slow-motion flyby, which peaked at a speed of 5,369 mph (8,640 km/h). "The images are stunning," says Tilmann Denk of the Free University in Berlin, who designed the Iapetus imaging campaign. "Every new picture contained its own charm."

The images show the dark material amounts to just a thin covering on the otherwise ice-rich surface. In some dark areas, even tiny, shallow craters punch through the veneer to the icy material below. Planetary scientists estimate the layer measures only 1 to 2 feet thick (0.3 to 0.6 meter).

More revealing information comes from the transition region between the white and black hemispheres. Seeing details as small as 33 feet (10m) across, scientists noted bright patches on slopes that face the poles and the bright hemisphere, while dark patches lie at crater bottoms and on slopes facing the equator and the dark hemisphere.

Although the slope preferences hint that heat plays a role in dividing Iapetus in two, actual temperatures confirm it. Cassini's Composite Infrared Spectrometer found the dark material to be relatively warm, up to –229° Fahrenheit (128 K), while the white material is as cold as –256° F (113 K).

Segregated by heat

Most Cassini scientists now think thermal segregation, an idea proposed a couple of years ago by John Spencer of the Southwest Research Institute in Boulder, Colorado, drives Iapetus' dual nature. The model starts with an ice-covered surface and a source of dark, reddish material that rains down on Iapetus.

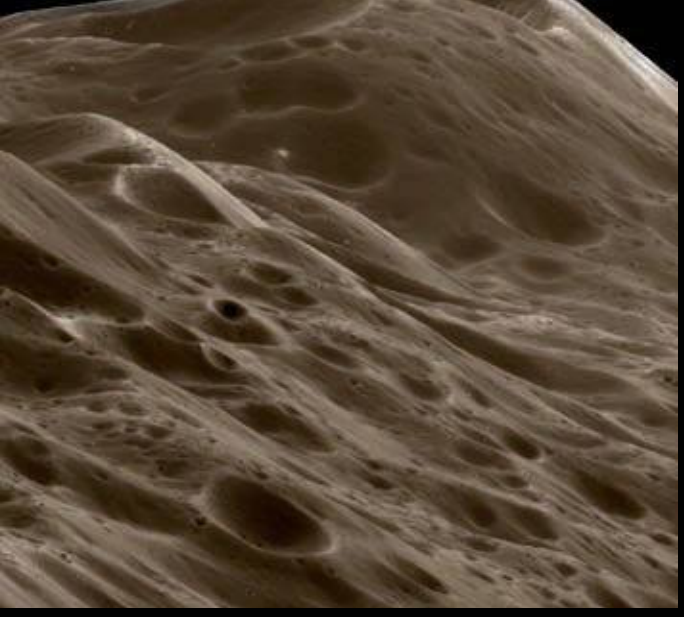
Because Iapetus rotates synchronously — taking the same 79.3 days to rotate as it does to circle Saturn — the moon always keeps the same face toward Saturn. (Our Moon does the same thing with Earth.) So, the incoming particles fall preferentially on the side of Iapetus that faces forward in its orbit, just as most raindrops hit the front windshield when you drive through a storm.

Synchronous rotation also exposes the dark material to 40 days of constant sunlight. This heats the dark material enough that its water ice turns directly into gas, or sublimates. The resulting water vapor then condenses on colder surfaces, near the poles or on the trailing hemisphere.

The dark stuff loses its surface ice and grows darker, while the bright regions accumulate ice and get brighter. The darker material then absorbs more sunlight, growing warmer in a runaway process. The 27° F (15 K) temperature difference between the two regions means material sublimates some 200 times faster from the warmer, darker regions.

Although thermal segregation solves part of the problem, it doesn't resolve the

Richard Talcott *is a senior editor of* Astronomy.



◀ **IAPETUS' EQUATORIAL RIDGE** stretches more than halfway around the moon and reaches heights of 12 miles (20 km). Cassini revealed the mountains to be crater-pocked, proving the ridge formed early in Iapetus' history. NASA/JPL/SSI

◀ **EVEN SMALL CRATERS** pack enough of a punch to penetrate the dark layer and reach the underlying ice. The thin surface covering may be only 1 foot (0.3m) thick. NASA/JPL/SSI

▲ **IAPETUS** awaited Cassini's arrival September 10. Bright ice hugs the moon's north pole, while a massive equatorial ridge appears at the slender crescent's far left. This false-color view enhances the dark material's reddish-brown hue. NASA/JPL/SSI

whole mystery: Planetary scientists still don't know where the dark material originates. Some think it comes from Phoebe, Saturn's outermost major moon. Micrometeoroids striking Phoebe's surface should dislodge dust that spirals inward and runs into Iapetus. However, Iapetus' dark regions have a reddish tinge, while Phoebe's surface is gray.

Other scientists think the material comes from even more distant, and much smaller, moons. But they may not be able to supply enough dark stuff. Still others think it may come from Hyperion, the next moon in from Iapetus, which suffered a violent disruption long ago. The material might even come from outside the Saturn system.

Of walnuts and ridges

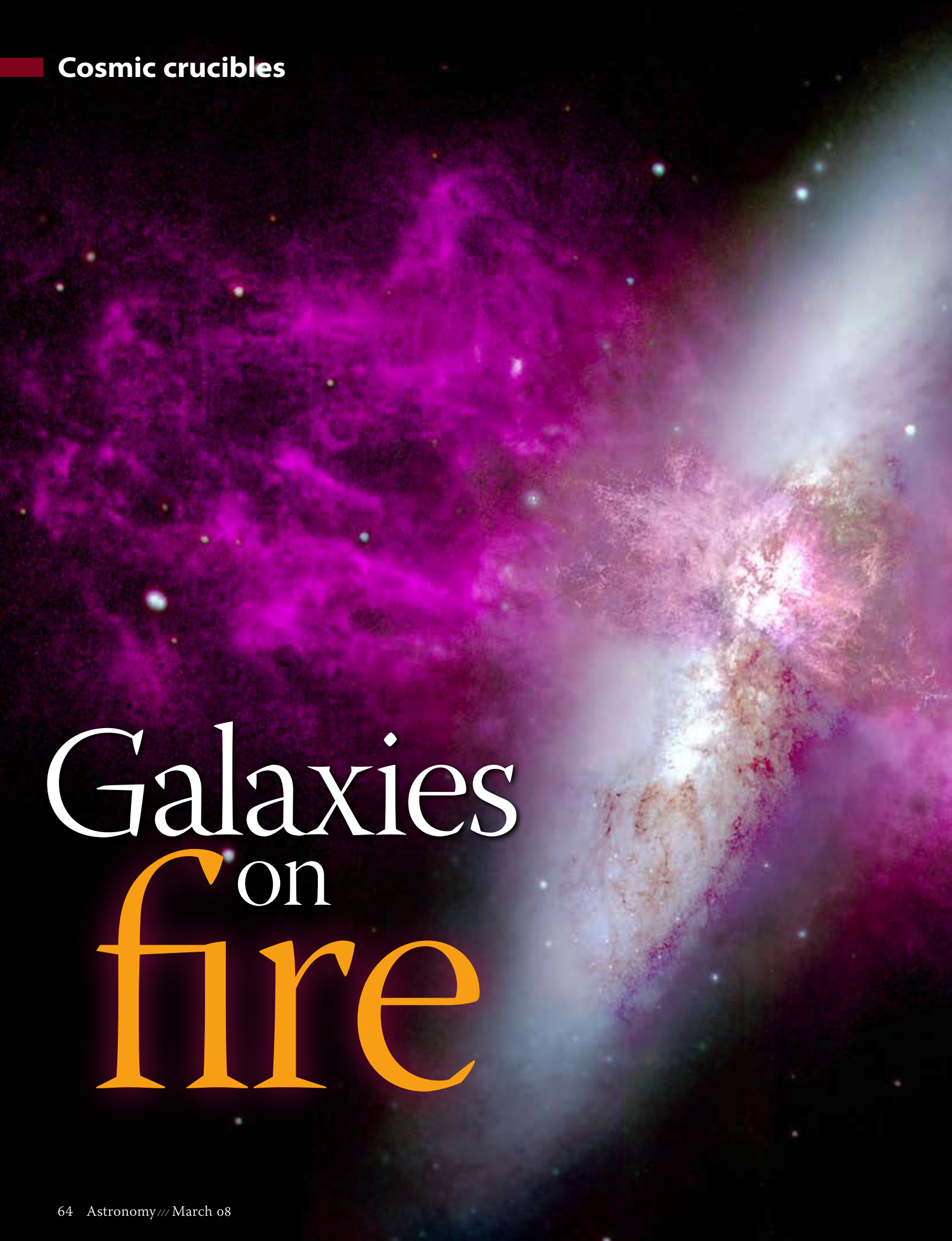
The Cassini flyby shed light on the mysterious ridge that extends around much of Iapetus' equator. The ridge, whose mountains reach heights of 12 miles (20 km), gives the moon a walnut shape. Cassini shows the ridge does not extend all the way around Iapetus. It breaks up into individual mountain peaks on the moon's trailing side, then disappears for nearly a quarter of the moon's circumference. Cassini proved the ridge dates from early in the solar system's history because numerous craters pit the terrain.

How the ridge formed, and why it doesn't circle the globe, remain open questions. Scientists may have figured out why the moon's equator bulges, however. Iapetus' equatorial diameter measures 44 miles (71 km) longer than its polar diameter.

Cassini scientist Julie Castillo of NASA's Jet Propulsion Laboratory led a team that thinks Iapetus froze into its current shape some 4.56 billion years ago. Then, the young moon rotated once every 16 hours and would have possessed the observed equatorial bulge.

Heat from the short-lived radioactive isotopes aluminum-26 and iron-60 quickly dissipated, however, and the moon grew rigid. "Iapetus spun fast, froze young, and left behind a body of lasting curves," says Castillo. Tidal forces from Saturn eventually slowed the moon into synchronous rotation.

Despite Cassini's remarkable findings, Iapetus has yet to divulge all its secrets. Unfortunately, Cassini won't make it back to Iapetus, even during the extended mission that will start when the primary mission concludes, in mid-2008. So, scientists will continue to pore over data from the September 10 flyby for years, trying to unravel the remaining puzzles of Saturn's weird, strange, and bizarre moon.



Galaxies on fire

Starburst galaxies hold the key to understanding processes that shaped the youngest and most distant corners of the universe. /// BY DANIEL PENDICK

Far, far away, 127 million light-years from Earth in the constellation Pisces, lies a faint and fuzzy galaxy, long observed but not very well understood until recently. You can find this object — a hazy, distorted spiral galaxy — just a hair northwest of the magnitude 5.9 star 16 Piscium. In 1888, back when astronomer J. L. E. Dreyer compiled his famous *New General Catalogue,* he labeled the galaxy NGC 7714.

At NGC 7714's heart lies a compact knot of star formation called a starburst. In this region, immense volumes of interstellar gas turn into massive, hot stars at an intensity 1,000 times greater than in a typical galaxy.

The big, hot stars explode as supernovae at a rate of one per decade, a far higher rate than in most galaxies in the local universe. The supernova swarm sets in motion a vast outflow of gas and dust — a superwind — from the galaxy's north and south poles.

The outflow spews supernova exhaust completely out of the galaxy's gravitational grip, fertilizing the intergalactic medium with elements that can be forged only in the hearts of stars, like carbon, oxygen, and silicon. Some of the "star stuff" that became the Sun and planets — and, ultimately, you and me — may have surfed into our corner of the universe on such a superwind.

Nearly a century after Dreyer added NGC 7714 to his catalog, astronomers identified it as the first of an entirely new class of astronomical objects: starburst galaxies. Soon thereafter, space telescopes exposed a surprising number of previously unrecognized starburst galaxies, many hiding within dusty veils.

Now, astronomers are finding that starburst galaxies and their humongous superwinds have a lot to teach us about how galaxies evolved and how the universe came to look the way it does today.

VAST OUTFLOWS OF GAS glow purple in this view of the dusty starburst galaxy M82. The outflows, collectively known as a superwind, exit at M82's poles, at the upper left and lower right of the central galactic disk. Superwinds fertilize the space between galaxies with heavy elements like carbon, oxygen, and silicon and influence galactic evolution.

Galaxy surprises

NGC 7714's journey from just another faint fuzzy in Dreyer's catalog to the first of a new category of galaxies paralleled developments in techniques for observing outside the realm of the merely visible.

From 1965 to 1980, astronomers at the Byurakan Astrophysical Observatory on Armenia's Mount Aragats rediscovered NGC 7714 during their comprehensive spectroscopic survey of the sky, the First Byurakan Survey. Thus the galaxy became known as Markarian 538, named after one of the astronomers working on the project.

Using a 1-meter Schmidt camera, Beniamin Markarian and colleagues Valentine Lipovetsky and Jivan A. Stepanian passed light from a telescope through a glass prism. The prism stretched the many pinpoints of light into multicolored smudges, or spectra. The technique allowed the First Byurakan Survey to collect the spectra of about 20,000,000 bright objects.

The survey snared many objects with unusual colors and inexplicable spectral fingerprints — like Markarian 538. Its core was strangely blue, shining brightly at ultraviolet wavelengths. In 1978, the International Ultraviolet Explorer satellite took a peek at NGC 7714 and gathered an even more detailed spectrum, including evidence of a strong gaseous outflow from the galaxy.

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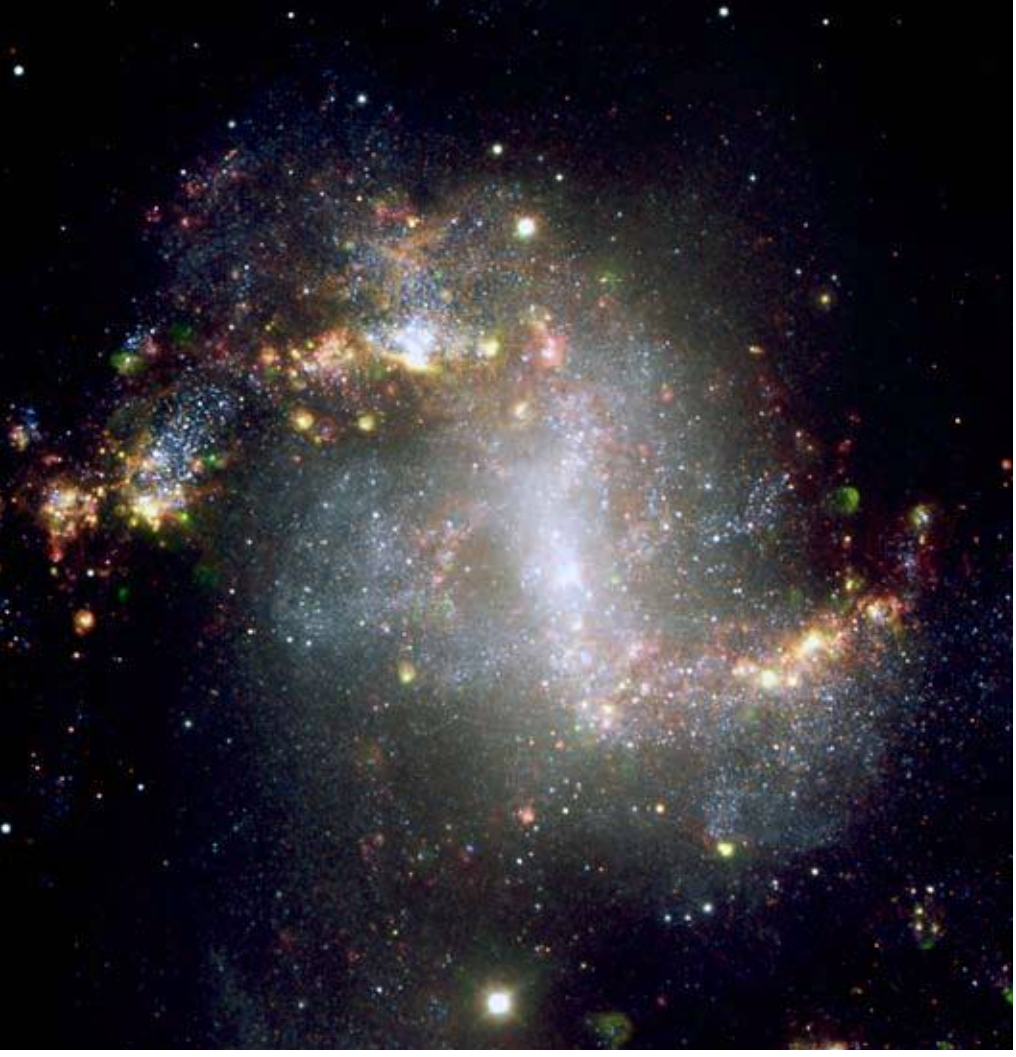


THE ODDBALL STARBURST GALAXY NGC 1313 presents an enigma. Unlike in typical starburst galaxies, much of NGC 1313's star birth occurs in its spiral arms, not its center. Astronomers don't know why. HENRI BOFFIN (ESO)

Hot stuff

In the 1970s, the newly discovered blue objects in the Markarian survey caught the attention of astronomers interested in the nature of galaxies with active galactic nuclei. These galactic cores emit extraordinary amounts of energy, and astronomers weren't sure why. One astronomer, Daniel Weedman (then at Pennsylvania State University), realized there was something different about NGC 7714's fiery nucleus.

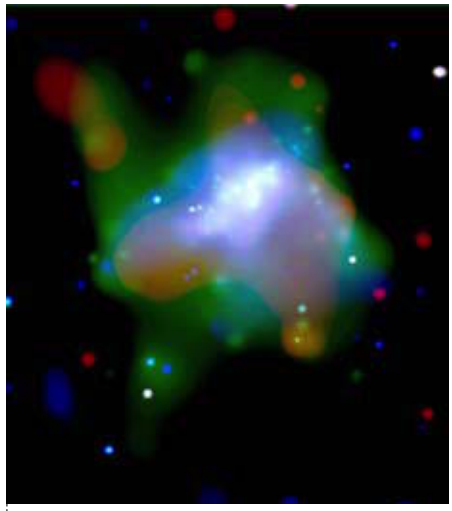
Weedman and his colleagues looked at all the data they had across the light spectrum, including optical, radio, X ray, ultraviolet, and infrared. They concluded NGC 7714's core contained a region of extremely rapid star formation and thousands of supernova remnants. They proposed a new category for NGC 7714: "star-burst galactic nucleus." This term later morphed into "starburst galaxy."

Daniel Pendick *is an associate editor of* Astronomy.

Not long after the First Byurakan Survey revealed enigmatic blue galactic nuclei, astronomers started seeing galaxies in a different color — infrared. This came after the 1983 launch of the Infrared Astronomical Satellite (IRAS), an orbiting observatory equipped with a 22-inch (57 centimeters) infrared telescope. (Infrared, light with wavelengths just longer than visible light, includes the radiant "heat" energy you feel from red-hot coals in an open fire.)

Astronomers already knew of infrared starburst galaxies, M82 being the classic example. Although M82 contains a compact starburst at its core, the galaxy overall is very dusty. The dust absorbs ultraviolet light streaming from hot, young stars in its core and re-radiates the energy as infrared.

IRAS revealed M82 was no oddball. "It found that M82 was just the nearest example of a whole big class of these things," says Timothy Heckman, an astrophysicist at Johns Hopkins University who studies starburst galaxies. "Suddenly we went from thinking of these starbursts as being somewhat interesting curiosities to the realization that a significant fraction of the star formation in the local universe was taking place in these galaxies."



C. MARTIN (UCSB/CALTECH)/H. KOBULNICKY (U. WISCONSIN)
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THE EXTENDED CLOUD of hot gas around dwarf galaxy NGC 1569 contains heavy elements forged in starbursts and supernovae. The gas emits X rays, making it visible to the Chandra Space Telescope.

Star power

IRAS and later instruments have greatly enriched our understanding of starburst galaxies. The most fundamental fact about a starburst galaxy remains its definition. "The simplest way to look at it is a galaxy that is undergoing a much higher rate of star formation than it did in the past," Heckman explains.

In the local universe — the galaxies nearest to us in space and time — starburst galaxies are in the minority. Yet, they produce about 10 percent of all new stars. Every year, typical spiral galaxies like the Milky Way convert a volume of gas 3 times the Sun's mass into stars. In the same period, a starburst galaxy might convert 30 solar-masses into stars in a volume of space 100 times smaller than the Milky Way.

"So the star-formation rate is 10 times higher in a volume 100 times smaller," Heckman says. "In the local universe, you only see this in starburst galaxies."

All starburst galaxies produce stars at a quick pace, but they are diverse. Astronomers have found starbursts in massive, dusty galaxies like M82, which emit mostly in the infrared. On the other end of the spectrum, starbursts occur in relatively dust-free dwarf galaxies, emitting mostly in

the ultraviolet. Others sit at intermediary points between these two extremes.

In the local universe, populated by large, mature galaxies like the Milky Way, most starbursts occur when two galaxies come too close for comfort. Whether a near miss, a glancing blow, or a full-scale merger, galaxy interactions concentrate gas and dust into a smaller space, triggering starbursts.

"To have a very elevated rate of star formation, it's necessary to concentrate the gas in the galaxy into a relatively small region," Heckman explains. "The denser the gas is, the faster it can turn into stars."

In a stable spiral galaxy, gas cannot easily flow to the center. That's because gas in the outer spiral arms has a lot of angular momentum due to the galaxy's rotation. To move toward the center, gas has to shed some of that momentum.

Encounters with other galaxies — even "close encounters" at a distance of 30,000 light-years — transfer angular momentum between the colliding partners. In the galaxy that loses momentum, gas flows toward the center, grows denser, and finally contracts to form stars.

"You need something dramatic to get a really big starburst," Heckman says. "The most spectacular starbursts we found with IRAS were not in normal-looking galaxies."

Early drama

To astronomers, most of the cosmic drama occurred in the first act — in the early universe, 3 to 4 billion years after the Big Bang. Then, gas-rich galaxies were merging, laying the foundations for the universe we see today. Along with the cosmic bumper-car ride came starbursts. In fact, starburst galaxies were the rule, not the exception, then.

THE STARBURST GALAXY NGC 7714, seemingly dwarfed by the bright star at left, revealed its vigorous star-forming core in a spectroscopic survey. It was the first galaxy officially recognized as a new type: starburst galaxy. ADAM BLOCK/NOAO/AURA/NSF

Heckman realized a few years ago that nearby starburst galaxies might reveal a lot about processes at work in the distant, early universe. "From a cosmological perspective, starburst galaxies are extremely interesting because they are, in a sense, local laboratories for studying processes that we think were important in the early universe," Heckman says.

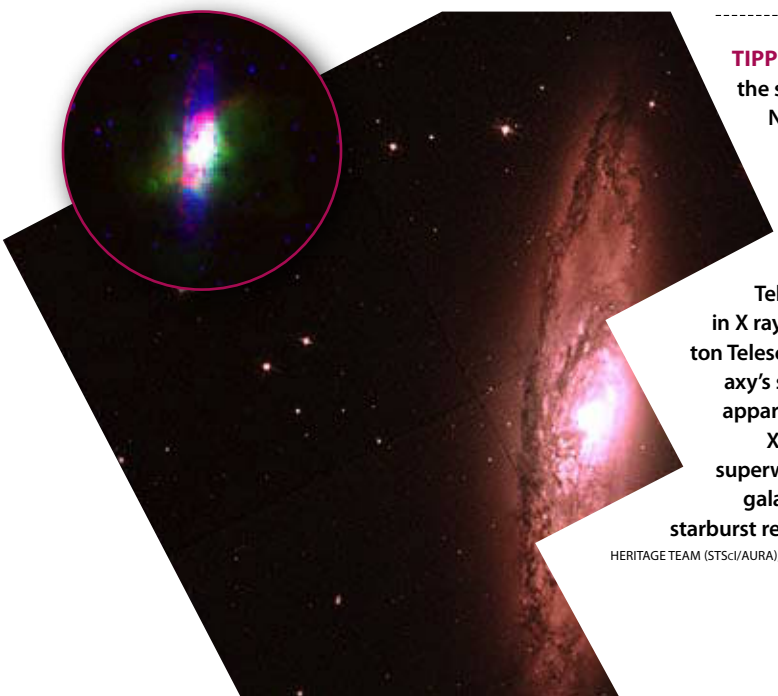
Local starburst galaxies are closer and brighter, and therefore easier to image and probe in detail. By contrast, distant galaxies are so faint that even the most powerful telescopes can't harvest the detailed information astronomers would like to have.

So Heckman and his colleagues started looking for starburst galaxies in the local universe with characteristics similar to those of distant galaxies. Then they applied for time on the Hubble Space Telescope to study the candidates and further narrow the field to the best analogs of distant starburst galaxies. Heckman, Johns Hopkins assistant research scientist Roderik A. Overzier, and 10 other European and American astronomers winnowed it down to eight galaxies.

Like galaxies in the early universe, the analogs show compact, rapid star formation. They have similar masses, sizes, luminosities, colors, and chemical compositions. And they have similar "global" structures: Their starbursts consist of one or several "knots" of star formation.

The Hubble observations highlight just how prolific are the starbursts in the local universe. "Each knot visible on the Hubble images contains millions of stars being born, some of which may be inside massive globular star clusters in the making," Overzier explains. "The Hubble images further show that these super starburst regions are triggered by collisions between relatively small galaxies."

What do they hope to see in the local analogs that they cannot easily learn from the most distant galaxies? "In order to



TIPPED nearly vertical in the sky, starburst galaxy NGC 1610 betrays no signs of gas outflow in this mosaic of optical images snapped by the Hubble Space Telescope. But imaged in X rays by the XMM-Newton Telescope (inset), the galaxy's superwind becomes apparent. Green indicates X rays emitted by the superwind; blue traces the galaxy's unusually wide starburst region. NASA/ESA/ THE HUBBLE HERITAGE TEAM (STScI/AURA); INSET: DAVE STRICKLAND/JOHNS HOPKINS UNIVERSITY

A PULSE OF STAR BIRTH ignited NGC 1569's core 25 million years ago. Brilliant blue star clusters dot the galaxy's dusty central disk. ESA/NASA/PETER ANDERS (GÖTTINGEN UNIVERSITY)

understand galaxy formation and evolution it is very important to understand the substructure of these distant galaxies," Overzier explains. "It makes a big difference to know whether one of these galaxies has a nicely formed disk or bulge, or whether it is a very complex, chaotic system of several starburst regions that are perhaps still building up the galaxy."

Of stardust and superwinds

Starbursts produce big, hot stars. Eventually, those stars exhaust their fuel, collapse, and trigger supernova explosions. If the supernova rate is high enough, it creates an outflow of gas and dust vigorous enough to escape the galaxy's gravitational influence.

Superwinds play an important role in galaxy evolution. Stars and supernovae forge elements heavier than hydrogen and helium. Superwinds remove heavy elements from galaxies in addition to hydrogen and helium and pump them into the vast intergalactic medium (IGM), the not-quite-empty space between galaxies. Loss of heavy elements from the galaxy can influence the composition of stars formed in subsequent generations.

But, more importantly, superwinds remove gas from galaxies that might otherwise be transformed into stars. The suppression of current and future star formation sculpts the galaxies' fates.

To test models of galaxy evolution, astronomers need more information on the IGM, such as its chemical composition and density. "The chemical properties of galaxies have an important impact on the way they look and evolve," says Caltech astrophysicist Charles Steidel. One of the things Steidel hopes to learn is how a galaxy's evolution changes as it loses heavy elements.

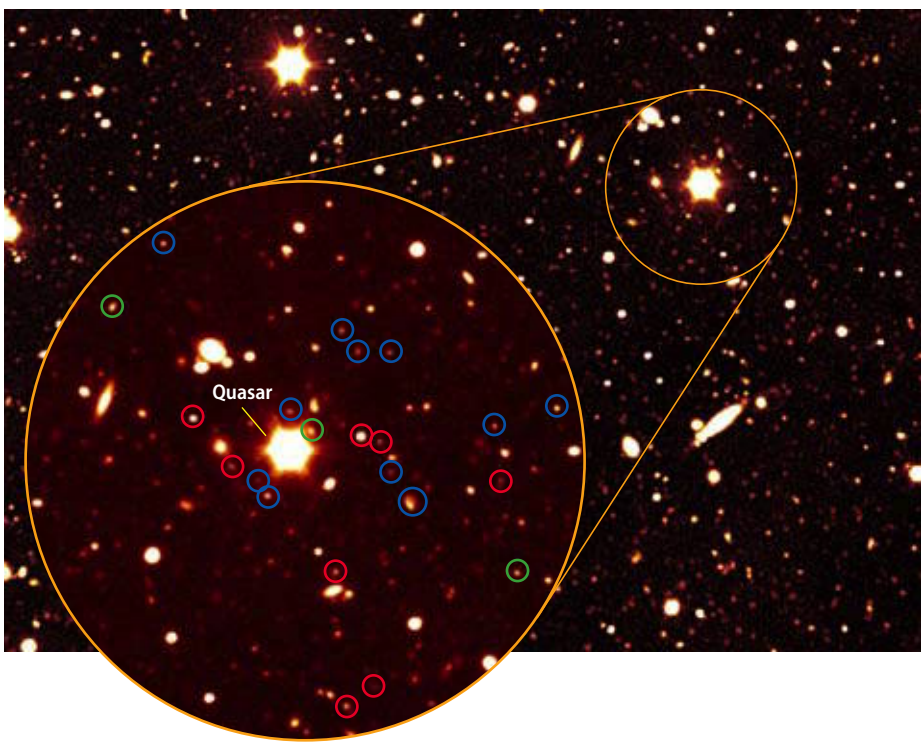
Galaxies at the breaking point

But the role of superwinds in cosmic history is obscured by a simple fact: Gas and dust in the IGM is largely invisible because it radiates no light of its own. It's cold and dark and, therefore, difficult to study. Steidel heads a team that found a way to probe the IGM in the early universe.

The first step is to locate distant galaxies as reference points for probing the gas and dust between them. Fortunately, Steidel helped pioneer a technique for rapidly identifying distant galaxies based on their spectroscopic signatures. It relies on special filters that pass only red, green, or ultraviolet wavelengths.

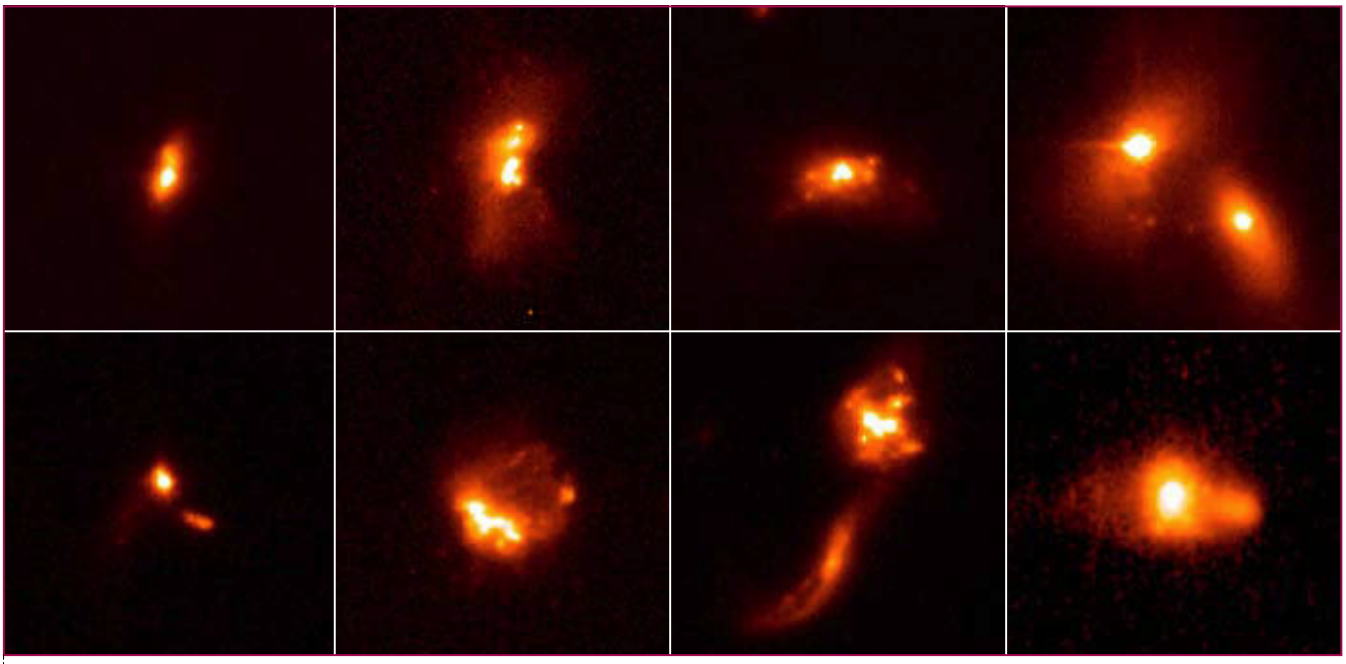
At great cosmic distances, the light from a galaxy is stretched, or redshifted, by the expansion of space itself since the Big Bang. The filters pass light from galaxies up to specific threshold distances. Beyond that point, the redshift of ultraviolet light at the threshold wavelength is so extreme that hydrogen gas in intergalactic space absorbs it all.

When an electronic detector senses the ultraviolet "drop out," astronomers know the light came from a galaxy at the predetermined redshift (or distance from Earth).



CHARLES STEIDEL (CALTECH)

DISTANT GALAXIES pack this star field imaged with the Keck I telescope. As a quasar's light passes through gas blown off by galaxies between the quasar and Earth (circled in blue), it records chemical information in its spectrum. Also shown are galaxies farther away than the quasar (green circles) as well as galaxies at the same distance as the quasar (red circles).



THE COMPACT, BRIGHT KNOTS of star birth stand out in Hubble images of eight nearby starburst galaxies. These and other features resemble those of much younger, distant galaxies. Astronomers hope to study these bright, nearby galaxies to understand galaxy evolution in the early universe. RODERIK A. OVERZIER & TIMOTHY HECKMAN (JHU)/G. KAUFFMANN (MPA)/NASA/ESA

This Lyman-break technique, named after the scientist who discovered the ultraviolet spectrum of hydrogen gas, has allowed Steidel and his colleagues to identify tens of thousands of high-redshift galaxies. They have taken detailed spectra on about 2,000 galaxies so far.

Light from these galaxies left when the universe was 10 percent of its current age. Without the Lyman-break method, identifying so many high-redshift galaxies would have taken far longer than it did. Fittingly, astronomers call the objects Lyman-break galaxies, or LBGs.

The other essential ingredients in Steidel's research is quasars — the glaringly bright nuclei of galaxies in the early universe. Light from quasars passes through the IGM on its way to Earth. Gas in the medium absorbs a certain set of wavelengths, impressing its chemical fingerprint on the quasar's spectrum.

If the gas is moving, it alters the quasar light, too. The quasar's intense light provides spectra 50 times more detailed than if the astronomers used the faint light of the LBGs themselves to probe the IGM.

The researchers compare the redshift of the quasar light to the redshifts of surrounding galaxies. This allows them to determine the location of the gas probed by the quasar light. Gradually, Steidel and his colleagues hope to build a 3-D portrait of the IGM between the Lyman-break galaxies in the first few billion years after the Big Bang, when galaxies were born.

"This is a way of getting much higher-quality information about what's going on in the gas, either in the outer parts of galaxies or gas that once was in galaxies and now is in the intergalactic medium," Steidel explains.

The technique also allows the astronomers to measure precisely how fast gas in the IGM is moving relative to the galaxies. "This tells us whether it's moving out of or into the galaxies, or whether it's sitting quiescently in the middle of nowhere," Steidel says.

Blown away

At the redshifts Steidel and his fellow researchers are working, the processes that shaped the galaxies we see today in the local universe were peaking. Galaxies were merging with each other, starbursts were bursting, superwinds were howling, and black holes were gobbling gas and growing rapidly.

"The main reason for wanting to do this is to understand galaxy formation," Steidel say. "I think of it as the time when fairly big galaxies formed most of their stars. So if you want to understand how that worked, this is the place to look."

Superwinds represented a critical feedback in the galactic ecosystem that shaped the stately spirals and egg-like ellipticals that populate the galaxy zoo. "In order to understand how galaxies work, you have to understand the reservoir of gas outside galaxies," Steidel says. "You're trying to look at the flow of gas in and out, and that's hard. It's one of the things we really don't understand yet. It's the missing link in galaxy formation."

Ultimately, Steidel's observations will show up in computer simulations of cosmic evolution. The models are not powerful enough to reproduce the massively complex interactions of gas and dust in the IGM. So modelers look to observers like Steidel to provide guidance and a telescopic reality check.

"At the moment, the theory of how galaxies form and evolve is mostly informed by the observations," Steidel explains. "The physics is too complicated even with a supercomputer to describe what is happening."

Someday, when the models are finally all gassed up, watch out for a veritable starburst of new understanding of galactic evolution. A

WEB EXTRA See the starburst galaxy M82 through Earth's great telescopes at www.Astronomy.com/toc.

ASK ASTRO

This month:
- Why is the corona the Sun's hottest part?
- Is the Hubble constant really constant?
- Does comet debris pose a hazard to the International Space Station?
- What is the difference between a planetesimal and a dwarf planet?

HOT CORONA

Q: Why is the Sun's corona so hot? — BRETT BILLMAIER, TEMPERENCE, MICHIGAN

A: The temperature in the Sun's atmosphere should drop as distance increases from the Sun's core — unless heat is added. But the corona, the Sun's outermost layer, is about 13 times hotter than our star's visible surface. What's going on? **Virtually all solar astronomers agree the answer involves the Sun's magnetic field.**

X-ray images of the Sun's corona indicate direct links between coronal heating and magnetic structures. Wave breaking and magnetic reconnection are the two basic mechanisms for coronal heating.

Wave breaking involves upward-moving waves that grow in amplitude as they move into the Sun's lower-density upper atmosphere. There, they produce shock waves and turbulence that can heat the corona. This phenomenon is similar to ocean waves breaking on a beach as the depth of the water decreases.

Magnetic reconnection involves twisting magnetic field lines to the point where they cross — and explosively release energy. Smaller-scale versions of the same mechanism can explain solar flares and coronal mass ejections. The final explanation of coronal heating may very well involve both wave breaking and magnetic reconnection. — **DAVID H. HATHAWAY,** NASA/MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

THE SUN'S CORONA is visible only during a total solar eclipse. Astrophotographer Michael Knowles of Mansfield, England, took this image from Side, Turkey, in 2006.

HUBBLE CONSTANT

Q: Does the Hubble constant change over time? — DAVID E. WEST, KENMORE, WASHINGTON

A: It does — which is why some prefer to call it a parameter. Measurements of the Hubble constant — the rate of the universe's large-scale expansion — continue to improve and push to earlier and earlier times. As we look toward more and more distant galaxies, the name "constant" becomes increasingly inaccurate.

Astronomers use supernovae — some of the brightest objects in the universe — to determine the Hubble constant at great distances. We determine a supernova's distance by comparing how bright it appears with how luminous it actually is.

We can also look at a supernova's spectrum to determine its redshift. Equating a nearby object's redshift as its "recessional velocity" is imprecise. It's more accurate to think of an object's redshift as a measure of the universe's relative size compared to its size today. Combining redshifts and "standard candle" brightness measurements tells astronomers how quickly the universe has expanded, which is directly related to the Hubble constant.

The most distant measurements we have are for supernovae that exploded when the universe was half its current size — when galaxies were about half as far from each other as they are today. Then, the Hubble constant was about 3 times greater than today's value of roughly 72 kilometers/second/megaparsec. Whether or not the Hubble constant will continue to decrease is a subject of intense observational scrutiny and theoretical attention. — **SIMON DEDEO,** KAVLI INSTITUTE FOR COSMOLOGICAL PHYSICS, UNIVERSITY OF CHICAGO

DANGEROUS DUST

Q: Does the debris left behind by comets pose a hazard to the International Space Station?

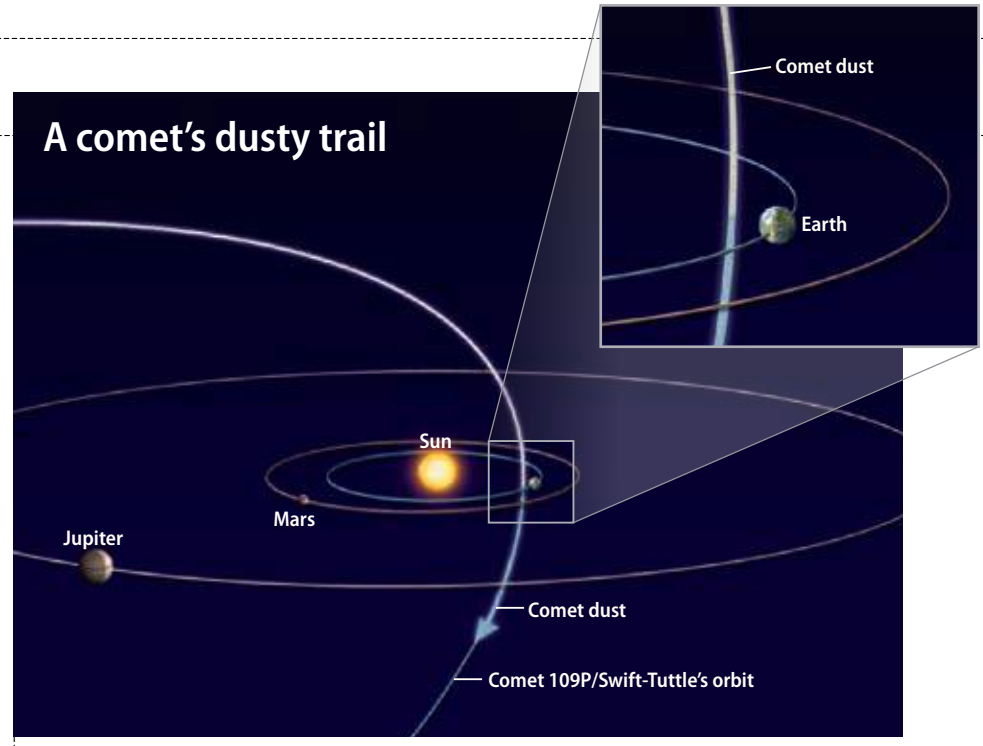
— **DEE SHARPLES,** HONEOYE FALLS, NEW YORK

A: Comet and asteroid debris pose a potential hazard to the International Space Station (ISS). Because of its size, the ISS is more likely to be hit by debris than are smaller spacecraft. Small particles frequently strike space shuttles and sometimes damage shuttle window panels.

Beginning in 1984, a school-bus-sized spacecraft called the Long Duration Exposure Facility (LDEF) spent nearly 6 years in orbit, exposing various materials to space impacts. After its return to Earth, scientists studied impacts on LDEF's exposed surfaces.

Chemical analysis of the impact residue indicates debris from orbiting satellites and their launch vehicles — like paint flakes, aluminum particles, or aluminum-oxide from rocket exhaust — poses a more significant collision hazard to satellites in low Earth orbit than do particles from comets or asteroids.

Shielding on the International Space Station protects its critical components, such as the habitation module, from impacting objects up to about 0.39 inch (1 cm) in diameter. The North American Aerospace Defense Command (NORAD) tracks orbital debris larger than about 4 inches (10 cm) in diameter. NORAD has tracked the orbits of more than 10,000 pieces of debris, and the International Space Station and space shuttles are maneuvered to avoid those objects. NASA assesses the risk of a critical International Space Station component being struck by debris in the 0.39-inch- to 4-inch-diameter (1 to 10 cm) range small enough to be acceptable. — **GEORGE FLYNN,** STARDUST SCIENCE TEAM AND STATE UNIVERSITY OF NEW YORK



A COMET LEAVES a trail of debris in its wake as it orbits the Sun. When Earth passes through the debris stream, orbiting spacecraft like the International Space Station also encounter these potentially destructive particles. *ASTRONOMY:* ROEN KELLY

BODY SIZE

Q: What is the difference between a planetesimal and a dwarf planet? — ROBERT ANTON, SANTA MARGARITA, CALIFORNIA

A: The term "planetesimal" refers to small bodies that orbited the Sun prior to the planets' formation. In 2006, the International Astronomical Union (IAU) ruled that a "dwarf planet" is a nearly spherical celestial body orbiting the Sun that has not cleared its orbital path of debris, as have the traditional planets.

The term "minor planet" was already an accepted catch-all for asteroids and Kuiper Belt objects. But Pluto is the only such object the Minor Planet Center in Cambridge, Massachusetts, kept tabs on that wasn't officially designated a minor planet.

Astronomers introduced the "dwarf planet" category during the 2006 debate to classify Pluto. But, Pluto aside, any definition that included "roundness" as a qualification also had to include Ceres, the largest asteroid, which is massive enough to make itself spherical; a few other large asteroids also may make the cut as astronomers better determine their shapes.

Moreover, the dwarf planets beyond Neptune will be classed in a separate, as-yet-unnamed category. Caltech astronomer Michael Brown points out that three of the four largest of these, including Pluto and Eris, have one or more moons, while only 11 percent of all Kuiper Belt bodies have moons.

So, while the new category is a bit puzzling linguistically, there is a physical basis for creating it. — **FRANCIS REDDY,** SENIOR EDITOR

COMING NEXT MONTH...
What's next for the Stardust spacecraft? Post your comments about this question online at www.Astronomy.com/forums.

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

IN THE KNOW

CORONA
The Sun's outer atmosphere.

HUBBLE CONSTANT
A measurement of the universe's large-scale expansion rate.

PLANETESIMALS
Small bodies that orbited the Sun prior to the planets' formation.

DWARF PLANET
A nearly spherical celestial body orbiting the Sun that has not cleared its orbital path of debris.

Binoculars allow observers to take in lots of sky. Now, Orion has improved the classic design. /// BY PHIL HARRINGTON

Orion's new binocular telescope tested

For the past 4 decades, I've lived by the creed that, for stargazing, two eyes are better than one. If you need convincing, Orion Telescopes and Binoculars makes a strong case with its BT70 binocular telescope. ❮ The BT70's 20x eyepieces capture 3.2° of sky thanks to their 63°

apparent fields of view. Each eyepiece focuses individually. Fold-out rubber eyecups and 15.5mm of eye relief make viewing comfortable, even if you wear glasses. The BT70 also comes with a removable handle, slide-out dew caps, and a sturdy, foam-fitted carrying case.

Although the BT70 eyepieces have larger diameters than standard 1¼" eyepieces, I found that by unscrewing the chrome barrels from a couple of my Plössl eyepieces, their housings matched the focusers. Unfortunately, while the eyepieces fit fine, the drawtube did not have enough in-travel to bring images into focus.

For those looking to expand the BT70's magnification range, Orion sells ancillary 16x and 25x eyepiece sets. The 16x eyepiece uses four lens elements to produce a 48° apparent field of view and 22mm eye relief. The resulting real field of view is 3°, slightly narrower than the included 20x. The 25x eyepieces rely on the same 5-element proprietary design as the 20x eyepieces to produce a 60° apparent field and 12.5mm eye relief. Their true field of view is 2.4°.

INTERCHANGEABLE EYEPIECES make these binoculars adaptable to a variety of astronomical targets. An eyepiece pair that yields 20x comes with each BT70.

The BT70 weighs nearly 9 pounds (4 kilograms), making an external support an absolute must. To address this need, Orion offers the BT70 with its alt-azimuth VersaGo mount. Although the VersaGo was not part of my test, it offers a viable option, as would a parallelogram mount.

For an observer to see the entire field of view, the spacing between a binocular's eyepieces must match the spacing between the observer's eyes. Conventional binoculars use a central pivoting hinge between the barrels, but this method is impractical for a right-angle design like the BT70.

Instead, Orion places an adjustment rod between the prism housings. Turning the conveniently located knob changes the interpupillary distance from a minimum of 2.38 inches (60.5 millimeters) to a maximum of 3 inches (76mm). The BT70 maintained alignment between the barrels across the full range of motion.

Along with their strengths, conventional binoculars have their drawbacks. Some observers lament that binoculars can be a pain in the neck, literally, when viewing objects high in the sky. Others wish they

Phil Harrington *is a contributing editor of* Astronomy *and the author of the observing guide* Star Ware *(Wiley, 2007).*

/// SPECIFICATIONS

BT70 BINOCULAR TELESCOPE

Objective lens diameter: 70mm
Magnification: 20x, with supplied eyepieces
Eye relief: 15.5mm
Focal length: 376mm
Field of view: 3.2°
Height: 12.2 inches (310mm)
Weight: 8 lbs. 15 oz. (4 kg)
Included: Removable handle, foam-fitted hard carrying case
Price: $649

THE BT70 binocular telescope provides high-quality optics, 2.8-inch (70mm) aperture lenses, and interchangeable eyepieces. ALL PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

CONTACT INFORMATION

Orion Telescopes and Binoculars
P. O. Box 1815
Santa Cruz, CA 95061
[t] 800.676.1343
[w] www.telescope.com

could change their binoculars' magnification. Wide fields of view are great, but let's face it; you wouldn't buy a telescope that worked at only one power. Different targets require different magnifications.

Orion's BT70 binocular telescope addresses both of these concerns. The handsome BT70 features an all-metal body, fully multicoated 70mm achromatic objective lenses, Porro prisms made of BaK-4 (barium crown) glass, and removable eyepieces. The BT70's integrated 90° prism assemblies make viewing near the zenith a pleasure. I really appreciate this feature.

ORION INCLUDES a foam-lined, aluminum case for transporting and storing the BT70.

The joy of two-eyed stargazing

Under the early winter sky, my first stop was the Orion Nebula (M42). The nebula put on a beautiful display. Image sharpness impressed me. The 20x magnification, combined with the BT70's excellent optics, proved just enough to crack the Trapezium into four tightly packed stars, not an easy test for this size instrument.

Each subsequent port of call proved equally breathtaking. I was especially impressed by views of the Pleiades (M45) in Taurus and the Double Cluster (NGC 869 and NGC 884) in Perseus.

During my optical testing, I found only a tiny bit of pincushion distortion, surprisingly little chromatic aberration (even while viewing a crescent Venus and the Moon), and no ghost images.

The view through the BT70 was sharp across the inner 80 percent of the field of view. Contrast and brightness also were excellent, with the clear, round exit pupils indicative of properly sized prisms and full-field illumination.

Enterprising owners might want to attach a red-dot finder to the BT70. I was able to sight along the handle fairly accurately, but a finder would make aiming easier. Although the handle's mounting shoe is not the same size as those used with many finders, an industrious observer could find a way of affixing a finder to the handle. Be sure to locate it far enough forward so your forehead doesn't hit it while viewing.

The Orion BT70 binocular telescope produced some of the most aesthetically pleasing views I've had in quite some time. If you're searching for a well-thought-out design with excellent optics, Orion has a winner here. In the end, two eyes are still better than one. A

WEB EXTRA Want to make the BT70 a go-to binocular? See www.Astronomy.com/toc for details.

BY GLENN CHAPLE

See double tonight

March is Messier Marathon time,

when observers in relatively low latitudes race in a single night to observe 109 objects cataloged by Charles Messier. But typical Messier objects like nebulae, clusters, and galaxies aren't the only worthy deep-sky targets. ☾ Double stars are the Rodney Dangerfields of the night sky: They "don't get no respect." But it wasn't always this way. In the 19th and early 20th centuries, when long-focus refractors ruled, double stars were the sky objects of choice. With the emergence of large reflecting telescopes in the mid-1900s, clusters, nebulae, and galaxies grabbed center stage.

Endless targets

So why bother with double stars? For one thing, they are plentiful. Astronomers estimate that at least half the stars in the night sky are multiple-star systems. Although most consist of stars too close to resolve using a backyard telescope, you can observe thousands of others through a 6-inch scope.

Data on double stars typically include the following:

The component stars' magnitudes (mag.). The brighter of the pair is called the primary; its partner is known as the secondary.

The separation (sep.) — distance — between the primary and secondary stars, in angular seconds of arc (″). Every degree (°) of a circle contains 60 arcminutes (′); each arcminute contains 60 arcseconds.

The "position angle" (P.A.) indicates the secondary's apparent sky position with respect to the primary. Straight north is 0°, east is 90°, and so on. The P.A. is especially useful when you want to locate a faint secondary.

Telescope requirements

Magnitude and separation determine which double stars you can resolve through a given telescope. To calculate the closest double star you can "split" — discern as two separate points — under ideal seeing conditions, divide 4.5 by your telescope's aperture in inches. This number, in arcseconds, is called Dawes' Limit.

IN A SMALL TELESCOPE or binoculars, the double star Gamma (γ) Andromedae resolves into a bright orange primary with its fainter secondary 9.6″ away.

ADAM BLOCK/NOAO/AURA/NSF

Hypothetically, a 3-inch scope should resolve double stars as close as 1.5″. However, faint doubles or pairs that differ greatly in magnitude don't obey Dawes' Limit. In such cases, your telescope's resolving limit may be several times Dawes' Limit.

Use enough magnification to separate the component stars comfortably. I like 100x or less for pairs wider than 6″, 100x to 200x for 2″ to 6″ pairs, and 200x and greater for double stars closer than 2″.

To split double stars separated by less than 1 arcsecond generally requires a scope with a 6-inch or larger aperture and high magnification (250x).

Start by observing this quartet of currently visible showpiece doubles. I promise they won't disappoint you:

Alpha (α) Geminorum (Castor). Mag. 1.9 and 3.0, sep. 4.2″, P.A. 62°

This striking binary pair comprises two stars that orbit each other every 467 years. Both are white. Alpha Geminorum is arguably the finest double star visible from northern latitudes. A magnitude 10 star located 71″ away (P.A. 164°) is connected gravitationally to Alpha Geminorum. Spectroscopy has revealed that all three stars are close binary pairs, making Castor a sextuple star!

Gamma (γ) Leonis (Algeiba). Mag. 2.4 and 3.6, sep. 4.6″, P.A. 127°

Another binary (period approximately 620 years), Gamma Leonis' primary is golden yellow.

Alpha (α) Ursae Minoris (Polaris). Mag. 2.1 and 9.1, sep. 18.6″, P.A. 233°

The North Star offers a small-scope light test. The components are widely separated, but the magnitude difference makes the secondary hard to glimpse in scopes smaller than 3 inches.

Iota (ι) Cancri. Mag. 4.1 and 6.0, sep. 30.7″, P.A. 308°

Observers often call this colorful duo the "spring Albireo" because of its rich yellow and blue hues.

For more double stars, check out 100 pairs listed on the Astronomical League's Double Star Club page (www.astroleague.org/al/obsclubs/dblstar/dblstar2.html) and the Saguaro Astronomy Club's top 110 doubles (www.saguaroastro.org/content/BEST-MULTIPLE-STARS.htm).

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com. Next month: The rewards of amateur astronomy. Clear skies!

WEB EXTRA See www.Astronomy.com/toc to learn more about angular distance and star color.

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There are two **TMB Optical** 80mm f/6.3 triplet apo refractors. The aluminum tube **TMB-80**, right, is $995. Never before has a genuine TMB apo been so attractively priced. Its fully multicoated apochromatic triplet lens uses premium FPL-53 ED glass. It has a rotating 2" Crayford focuser, 1.25" and 2" compression ring eyepiece holders, and a *free* $120 value Astro-Tech 2" dielectric star diagonal. A true TMB apo refractor for under $1000? Wow!

TMB-80CF carbon fiber triplet apo **$1395**

TMB-80 triplet apo **$995**

The **TMB-80CF**, above left, uses the same 80mm triplet FPL-53 apo optics, but in a unique, lightweight (only 4.35 pounds), and incredibly strong carbon fiber body. It also includes a Starlight Instruments *Feather Touch* 2" dual-speed Crayford focuser.

The very compact 92mm f/5.5 **TMB-92** triplet apo, below, fills the void left by the discontinued 90mm Astro-Physics Stowaway (a legendary scope that sells for up to $6000 on the used market). But you won't pay $6000 for the TMB-92. This fast f/ratio TMB is only $1999. The TMB-92 has a collimatable lens cells and a famous *Feather Touch* 2.7" dual-speed rotating rack and pinion focuser.

TMB-92 triplet apo **$1999**

For answers to your telescope questions, visit the forums at *www.cloudynights.com*

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TV-76 optical tube, green or ivory finish	1750.00	*1320.00*	**1190.00**
TV-76 package, green or ivory finish	2275.00	*1725.00*	**1550.00**
TV-85 optical tube, green or ivory finish	2250.00	*1750.00*	**1575.00**
TV-85 package, green or ivory finish	2775.00	*2150.00*	**1935.00**
TV-85 package, brass body	3295.00	*2550.00*	**2295.00**
NP-101 package	4900.00	*3685.00*	**3295.00**
NP-101is Imaging System optical tube	5300.00	*3985.00*	**3585.00**
TV-102 optical tube	3350.00	*2250.00*	**1995.00**
TV-102 package	3900.00	*2685.00*	**2395.00**
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Now you can *see* them close-up, too – not just a picture on a tiny LCD screen, but the actual celestial object itself. The **Celestron SkyScout Scope 90** is an economical 90mm altazimuth achromatic refractor with a special bracket that holds an optional SkyScout. Once the SkyScout has identified or led you to a solar system or deep space object, you can view it through the scope's 16.5x and 66x eyepieces. Scope 90 and SkyScout will open up a whole new universe of enjoyment for you.

Celestron SkyScout Scope 90 **$299** Shown with optional Celestron SkyScout

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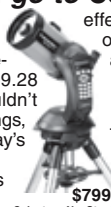

$799 **Celestron NexStar SSE** 5" Schmidt-Cassegrain

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BY PHIL HARRINGTON

Take a small tour of the Big Dog

Whenever I observe this time of year,

I enjoy revisiting the three brilliant stars of the Winter Triangle: Rigel, Procyon, and Sirius. Through binoculars, Sirius is especially dazzling. Depending on the steadiness of Earth's atmosphere, it may look like a radiant pure white diamond. Or, if the air is turbulent, it can sparkle with nearly every color in the rainbow.

As you're admiring Sirius through your binoculars, can you also see a misty patch near the bottom of the field? Surprise! You've just found the open cluster **M41** (NGC 2287).

I call M41 the "Dog Tag Cluster" for its position near the canine's "neck." Under dark skies, 10x50 binoculars show about a dozen faint points shining within the dim glow of unresolved cluster stars.

Unfortunately, light pollution and haze can annihilate this puff of stardust if you view it too low in the sky. M41 is highest above the southern horizon in March immediately after the sky darkens. Make it the first stop on your next observing run.

Continuing from Sirius about half a 10x50 binocular field southward along the Dog's back, you'll come to the stars **Omicron 1** (o^1) and **Omicron 2** (o^2). Yellowish Omicron 1 is the brightest member of the sparse open cluster Collinder 121, which lies about 2,400 light-years from Earth.

Owing to its star-filled surroundings, Collinder 121 is much tougher to recognize than M41. Look carefully for a pair of 6th-magnitude suns just south of Omicron 1, and a few 7th-magnitude-and-fainter stars scattered to the north and west.

THE BRIGHTEST STAR in Canis Major, Sirius, forms one of the Winter Triangle's three corners. *ASTRONOMY:* ROEN KELLY

Hop another half a field southeast to 2nd-magnitude **Wezen** [Delta (δ) Canis Majoris], the Dog's tailbone. Then continue up and over half a field northeast to 4th-magnitude **Tau (τ) Canis Majoris.** Tau is the brightest star in the open cluster **NGC 2362.** Unfortunately, light from this beacon overwhelms the other 40 or so tightly packed cluster stars you'll see through binoculars with less than 10x magnification. However, a few peek through my 16x70s.

NGC 2362 is only 5 million years old, making it one of the youngest star clusters known. Tau, a blue supergiant, is the brightest cluster member by far, shining 50,000 times brighter than our Sun.

From Tau and NGC 2362, look about one binocular field due east for the 3rd-magnitude star **Xi (ξ) Puppis** and one of its apparent companions, 5th-magnitude SAO 174592. Both of these yellowish suns contrast colorfully against a field strewn with blue-white stars. It turns out, however, that this pairing is just an illusion. Xi lies about 1,350 light-years from Earth, while its "companion" is only 300 light-years away.

If you have a sharp eye, you should also notice the dim glow of **M93** (NGC 2447) looking like a small ball of celestial cotton northwest of Xi. Discovered 227 years ago by Charles Messier, M93 holds about 80 stars in its gravitational grip.

Although you'll need a telescope to get a detailed view of those stars, dark skies and steadily held 50mm binoculars should reveal about a half-dozen distinct points mixed among a dim mist that, to my eyes, looks triangular.

March madness

Finally, if it's March, then it must be time once again for March Messier Marathon Madness. Every year around the vernal equinox, the Sun is positioned such that all Messier objects are visible sometime during the night. If you'd like to try a Messier "Bino-thon" yourself, visit the web extra this month at www.Astronomy.com/toc to obtain a sequential checklist of objects.

Next month, we'll pay a short visit to Hydra, the sky's longest constellation.

WEB EXTRA Download a checklist of Messier Marathon objects for binoculars at www.Astronomy.com/toc.

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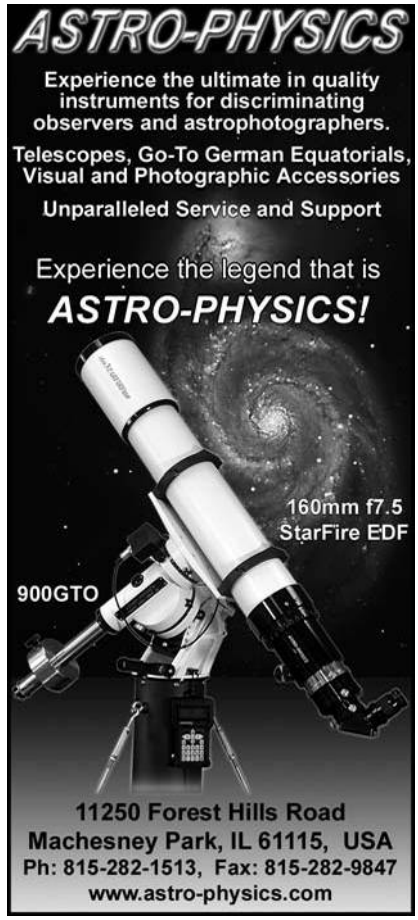

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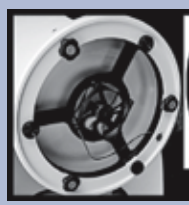

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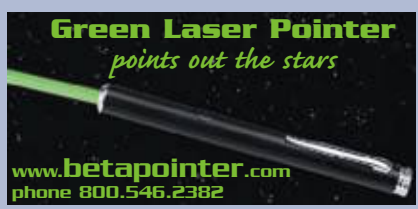

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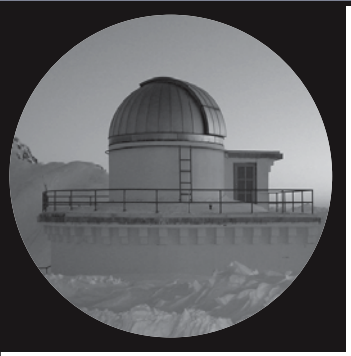

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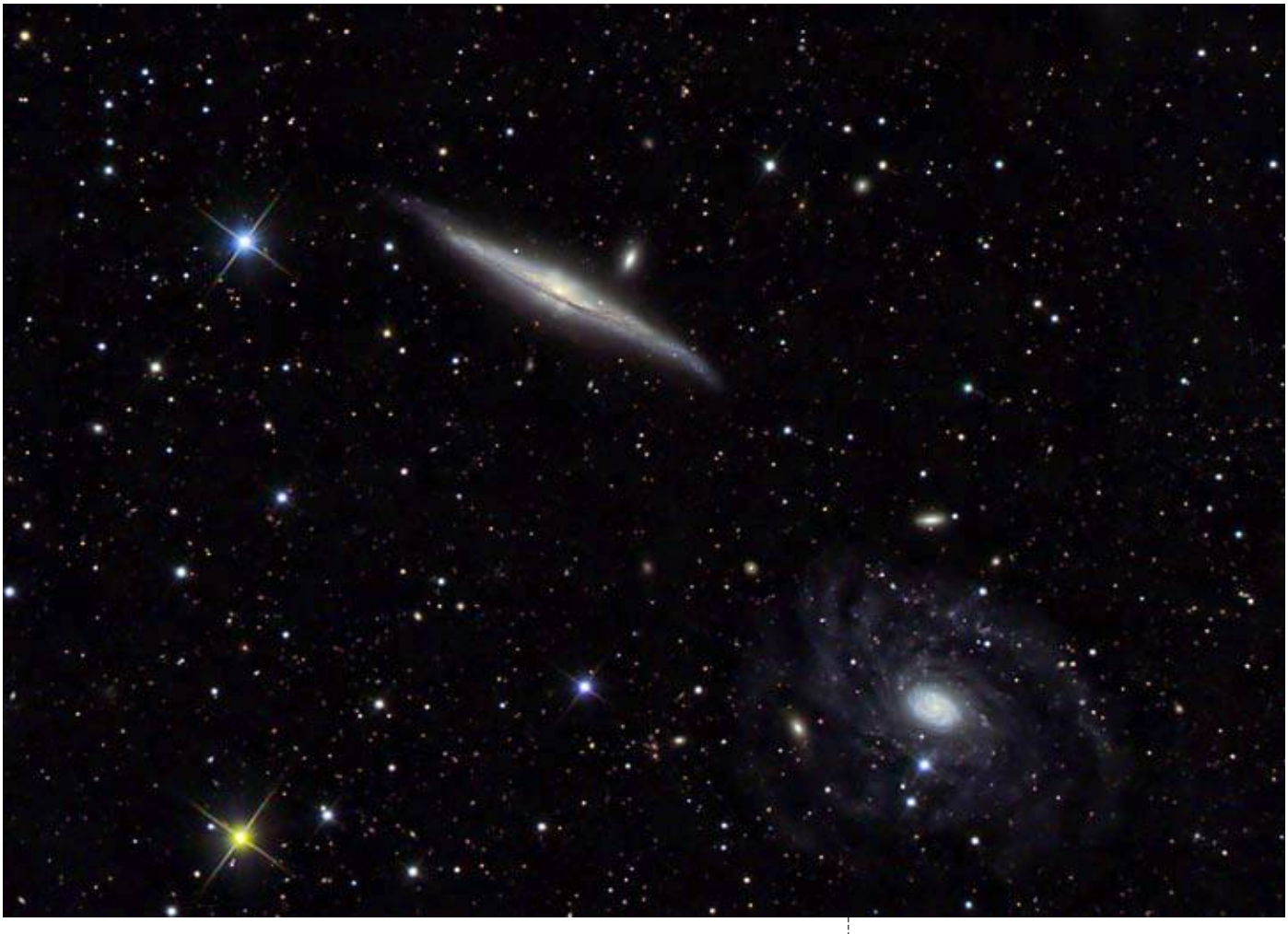


NGC 5963 AND NGC 5965 (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.3, Yankee Robotics Trifid II 6303E CCD camera, Astrodon filters, LRGB image with exposures of 420, 210, 210, and 255 minutes, respectively) /// **KEN CRAWFORD, RANCHO DEL SOL CAMINO, CALIFORNIA**

SPECIAL GALAXIES GALLERY

Celestial dynamic duo

What better way to end this special issue than with a selection of galaxy images from our contributors? This 2-for-1 image by Ken Crawford combines the face-on spiral NGC 5963 with the edge-on system NGC 5965, both of which lie in Draco. NGC 5963 glows at magnitude 12.3, and NGC 5965, which lies 9' north-northeast of its companion, is a bit brighter at magnitude 11.9. NGC 5965 is one of 20 spiral galaxies with large central bulges that a team of astronomers studied with the Hubble Space Telescope. They found the bulges appeared early in the galaxies' formation.

HOAG'S OBJECT, a peculiar ring galaxy in Gemini, looks like a planetary nebula through a telescope. It lies 600 million light-years away. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.4, SBIG ST-10XME CCD camera, LRGB image with exposures of 100, 20, 20, and 20 minutes, respectively) /// **ADAM BLOCK/NOAO/AURA/NSF**

THE SIAMESE TWINS (NGC 4567 and NGC 4568) are interacting spiral galaxies in Virgo. The pair lies about 120 million light-years away. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.3, Yankee Robotics Trifid II 6303E CCD camera, Astrodon filters, RGB image with 90-minute exposures through each filter) /// **KEN CRAWFORD, RANCHO DEL SOL CAMINO, CALIFORNIA**

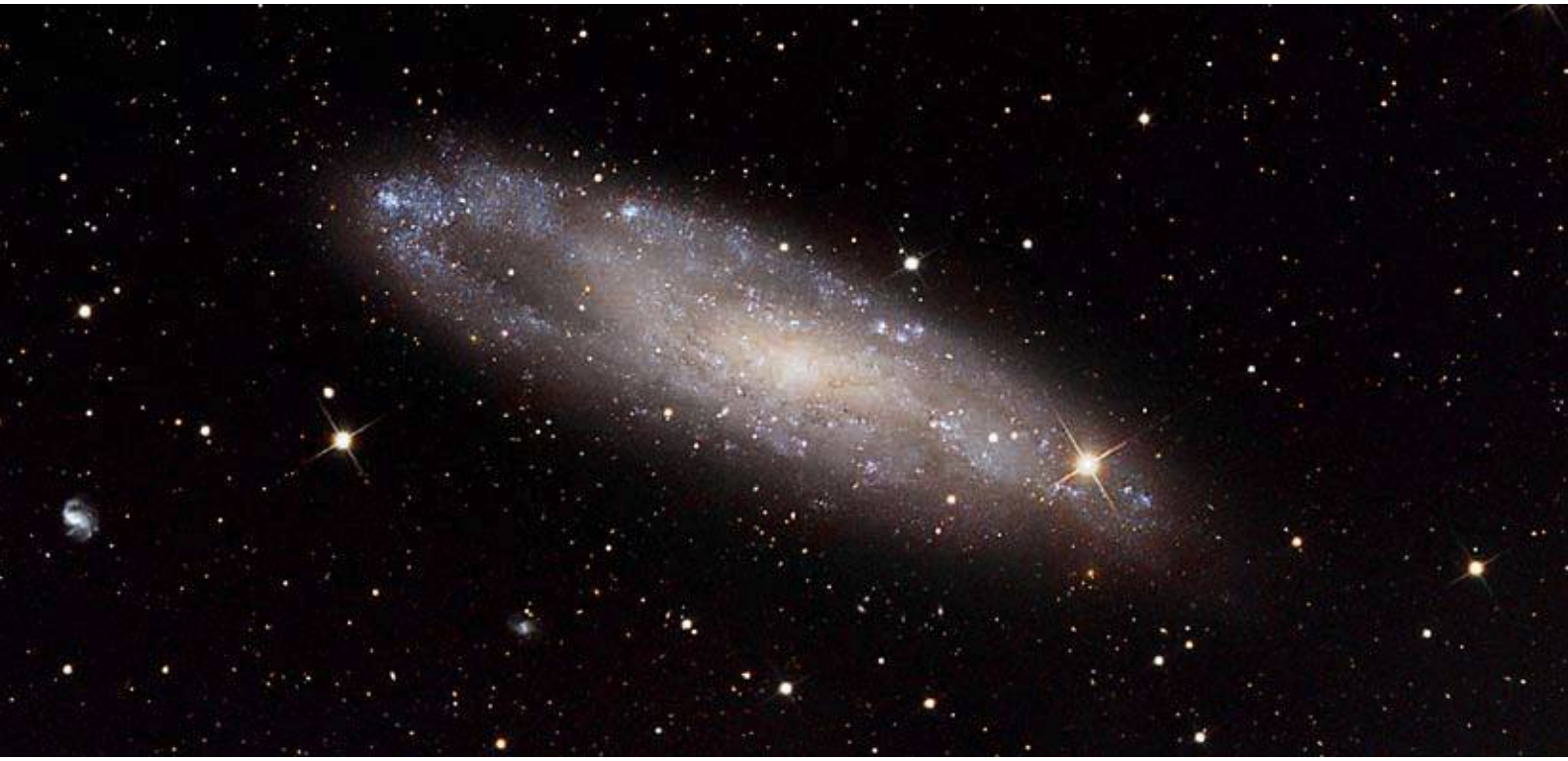
SPIRAL GALAXY M109 in Ursa Major is the last object in Messier's catalog. It glows at magnitude 9.8 and lies just 40' southeast of magnitude 2.4 Phecda (Gamma [γ] Ursae Majoris). (12-inch Meade LX200R advanced Ritchey-Chrétien telescope, SBIG ST-10XME CCD camera, LRGB image with exposures of 225, 25, 25, and 25 minutes, respectively) /// **RUBEN KIER, ORANGE, CONNECTICUT**

NGC 1097 in Fornax lies near the southern horizon for many Northern Hemisphere observers. This classic barred spiral galaxy shines at magnitude 9.5. (20-inch and 12-inch RC Optical Systems Ritchey-Chrétien telescopes, SBIG STL-11000 CCD camera, LRGB image with exposures of 595, 225, 135, and 270 minutes, respectively) /// **R. JAY GABANY, SAN JOSE, CALIFORNIA**

Send your images to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of image and complete photo data: telescope, camera, and exposure information. To submit images electronically, visit www.contribute.kalmbach.com.

SPIRAL GALAXY IC 239 in Andromeda shines faintly at magnitude 11.9 and competes with foreground stars. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.4, SBIG ST-10XME CCD camera, LRGB image with exposures of 120, 20, 20, and 20 minutes, respectively) /// **SHARON KEMPTON AND KAREN BRISTER/ ADAM BLOCK/NOAO/AURA/NSF**

M100 IN COMA BERENICES represents a grand-design spiral galaxy (one with well-developed spiral arms). It lies 60 million light-years away and is a member of the Virgo cluster of galaxies. (16-inch Meade Schmidt-Cassegrain telescope at f/5.5, SBIG ST-2000XCM CCD camera, LRGB image with 375 minutes total exposure time) /// **FILIPPO CIFERRI, ROME**



SPIRAL GALAXY NGC 247 in Cetus belongs to the nearby Sculptor group of galaxies. At magnitude 9.8, it shows lots of details through 8-inch or larger telescopes. (14.5-inch RC Optical Systems Ritchey-Chrétien telescope at f/9, SBIG STL-11000 CCD camera, LRGB image with exposures of 120, 60, 60, and 60 minutes, respectively) /// **DANIEL VERSCHATSE, ANTILHUE OBSERVATORY, CHILE**

SPIRAL GALAXY NGC 3521 in Leo often gets overlooked for brighter galaxies nearby. NGC 3521 is a "flocculent" galaxy because of its short, patchy spiral arms. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.3, Yankee Robotics Trifid II 6303E CCD camera, Astrodon filters, LRGB image with exposures of 140, 135, 135, and 170 minutes, respectively) /// **KEN CRAWFORD, RANCHO DEL SOL CAMINO, CALIFORNIA**

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